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Dissolved Gas Abatement Studies

Design of Deflectors for Little Goose Spillway, Snake River, Oregon

A Physical Model Study

Steven C. Wilhelms and Laurin I. Yates

June 2017

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Abstract

Based on the results of the Dissolved Gas Abatement Studies, spillway deflectors were recommended for the exterior bays of the Little Goose Spillway to reduce total dissolved gas production during spill operations. The design of the deflectors was developed by examining their hydraulic performance in a 1:40-scale section model of the spillway. Four different deflector designs were compared relative to flow conditions in the stilling basin and tailrace area of the section model. The authors recommend the design of the existing deflector, designated Type I, which is 8 feet (ft) long at elevation 532.0 (National Geodetic Vertical Datum) with no transition radius for the exterior bays at Little Goose Spillway. There was essentially no difference in the performance character of the Type I deflector and the Type II deflector (12 ft long without transition radius) over the design discharge range of 7,000–10,000 cubic feet per second per spill bay. Velocities, as high as 17 ft/second, were measured along the tailrace channel bottom. Detailed hydrographic survey data should be taken in the stilling basin and tailrace to assess changes in bathymetry caused by potential scour or ball-mill grinding.

Contents

Figures and Tables

Figures

Tables

Preface

The U.S. Army Engineer District, Walla Walla (NWW), authorized this physical model study, which was conducted under the Dissolved Gas Abatement Studies (DGAS) Program and co-sponsored by NWW and U.S. Army Engineer District, Portland District. The study was conducted from January 2000 to August 2001. Sean Milligan was the primary NWW point of contact. Mark Lindgren was the Chief, Hydraulic Design Section, and Rick Emmert was the NWW DGAS study coordinator.

Dr. Steven C. Wilhelms, Coastal and Hydraulics Laboratory (CHL), U.S. Army Engineer Research and Development Center (ERDC), was the principal investigator for the study. Calvin Buie (CHL) assisted in model operation and data collection. Lauren Yates (CHL) assisted in preparation of memoranda and in data reduction, analysis, and presentation.

John F. George was Chief, Inland Hydraulics Structures Branch, CHL, and helped coordinate the effort. During the studies, Dr. James R. Houston was the Director, CHL, and Dr. Robert W. Whalin was the Director of ERDC.

At the time of publication of this report, José E. Sánchez was the Director of CHL, and Jeffrey R. Eckstein was the Deputy Director of CHL.

COL Bryan S. Green was the Commander of ERDC, and the Acting Director of ERDC was Dr. David W. Pittman.

Unit Conversion Factors

Multiply	By	To Obtain
cubic feet per sec, ft^3/s	0.0283	cubic meters per sec, m^3/sec
feet	0.3048	meters

Executive Summary

The operation of spillways on the Columbia and Snake Rivers causes the absorption of atmospheric gases (chiefly nitrogen and oxygen) to supersaturated levels that often exceed the acceptable total dissolved gas (TDG) levels set by state and national standards. As a consequence of the supersaturated TDG, migrating salmonids may suffer gas bubble trauma, where bubbles form in their blood stream, sometimes causing death. To address this issue and develop alternatives to reduce TDG at the spillways, the Dissolved Gas Abatement Studies (DGAS) program was initiated. The overall purpose of the DGAS program was to develop structural and operational alternatives to decrease the dissolved gas levels generated during spillway operations. Several potential alternatives were identified and assessed through lengthy analyses and evaluation of historic TDG data from the river, site-specific field studies, and physical models concerning their gas exchange characteristics.

At the Little Goose Spillway, deflectors had been installed on the interior spill bays several years earlier, leaving the two exterior bays with discharge plunging into the stilling basin. As a consequence of the highly aerated plunging flow, significant TDG uptake was occurring with these bays in operation. Thus, a physical model study was authorized to design and locate the deflectors on the outside spill bays. A 1:40-scale “section” model of the Little Goose Spillway was selected to develop the deflector design. The model consisted of two bays and one half-bay of the Little Goose Spillway and a short section of the non-overflow portion of the dam. The model will serve as a flow visualization tool to evaluate vertical and longitudinal flow patterns generated by structural or operational alternatives for various flow rates.

Several designs were evaluated in the section model that included the following deflectors: (1) existing and (2) with and without transition radii.

- Type I: Existing spillway deflector, 8-feet (ft)-long , no transition radius
- Type II: 12 ft long deflector, no transition radius
- Type I-b: 8 ft long deflector, 10 ft transition radius
- Type II-b: 12 ft long deflector, 15 ft transition radius

Discharges in the study ranged up to 19,600 cubic feet per second (19.6 kcfs) per spill bay, which would result in 157 kcfs in total spillway discharge for uniform gate openings. Tailwater was varied to examine the

resulting flow conditions in the stilling basin and tailrace. Hydraulic performance was classified into several categories depending upon the action in the stilling basin. The categories and a brief description of the hydraulic action follow:

- Category 1: Plunging flow including vented plunging flow, unstably vented plunging flow, non-vented plunging flow
- Category 2: Unstable or surging flow
- Category 3: Skimming flow or surface jet
- Category 4: Undulating flow or an undulating surface jet
- Category 5: Ramped surface jet
- Category 6: Surface jump
- Category 7: Submerged surface jump

The flow conditions that limit plunging action in the stilling basin provide the best opportunity to reduce TDG absorption. Thus, Category 3 with a skimming surface jet is the best condition for reducing the plunging action. However, Category 4, and to lesser degree, Category 5, although not ideal, should also reduce plunging action compared to undeflected flow and the other categories.

Based on the study and the comparison of the performance characteristics of the four deflectors, the existing Type I deflector at elevation (el) 532.0[1] is recommended for the exterior bays at Little Goose Spillway. There was essentially no difference in the performance of the Type I deflector and the Type II deflector over the design discharge range of up to 10.0 kcfs per spill bay. The Type I-b and Type II-b deflectors demonstrated a narrower range of tailwater elevations for a skimming and undulating surface jet and are, therefore, not recommended. Additionally, velocities, as high as 17 ft per second (ft/sec), were measured along the tailrace channel bottom in the circulation cell under the surface jets. Because of this relatively high upstream velocity along the bottom, the authors recommend that a close check be kept on the possibility of erosion in the stilling basin or immediate tailrace. Detailed hydrographic survey data should be taken in the stilling basin and tailrace to assess changes in bathymetry caused by scour or ball-mill grinding.

[1] Elevations are referenced to the National Geodetic Vertical Datum (NGVD).

1 Introduction

Background

The operation of spillways on the Columbia and Snake Rivers causes the absorption of atmospheric gases (chiefly nitrogen and oxygen) to supersaturated levels. For many operations, the TDG levels exceed state and national standards in the tailrace and river downstream of the projects. The highly aerated plunging flow in the spillway stilling basin transports enormous volumes of entrained air bubbles to the depth of the stilling basin. The added hydrostatic pressure of the depth causes accelerated absorption of TDG to supersaturated levels. As a consequence of the supersaturated TDG, aquatic life, particularly migrating salmonids, may suffer gas bubble trauma, where bubbles form in their blood stream, sometimes causing death. To address this issue, the DGAS program was initiated.

The overall purpose of the DGAS program was to develop structural and operational alternatives to decrease the dissolved gas levels generated during spillway operations on the Snake and Columbia Rivers. The assessment of DGAS alternatives was conducted through analysis of historic data from fixed shore-based monitoring stations, site-specific prototype field studies, physical models, and analytical investigations concerning gas exchange at hydraulic structures.

From the DGAS program, spillway deflectors were identified as one of the most attractive and least expensive alternatives for preventing plunging flow and thereby reducing absorbed TDG. At Little Goose Spillway, the six interior spillway bays had deflectors, which left intact the plunging action of the flow from the two exterior bays that did not have deflectors. As a consequence, increased TDG occurred in the tailrace area and farther downstream. Therefore, spillway deflectors were adopted for the exterior bays to further reduce the TDG in the Snake River. To maximize the TDG reduction, a physical model study was authorized to visualize the stilling basin flow conditions and reduce the plunging action. Based on these observations, the design of the spillway deflector (shape and vertical location) would be determined. This special report summarizes the results of this physical model study, which is documented in much greater detail in the memoranda that are included as appendices.

Objective and scope

The overall objective of this physical model study was to evaluate the performance of the existing spillway deflectors at Little Goose Spillway and determine if an alternate design could provide improved performance over a wider range of spillway discharges and tailwater elevations. Because the plunging action of spillway flow causes the absorption of TDG, the optimum flow condition would be a surface jet with little or no plunging action. This will not likely eliminate but minimize TDG absorption. To examine the flow conditions in the stilling basin and immediate tailrace, a portion of the Little Goose Spillway was reproduced in a physical model. This “section” model of the spillway consisted of two bays and one half-bay of the spillway and a short section of the non-overflow portion of the dam at the powerhouse. The vertical flow patterns set up in the stilling basin and tailrace by alternate deflector designs could easily be determined with the section model. As described earlier, of specific interest, are the flow conditions that limit the plunging action of the spillway discharge.

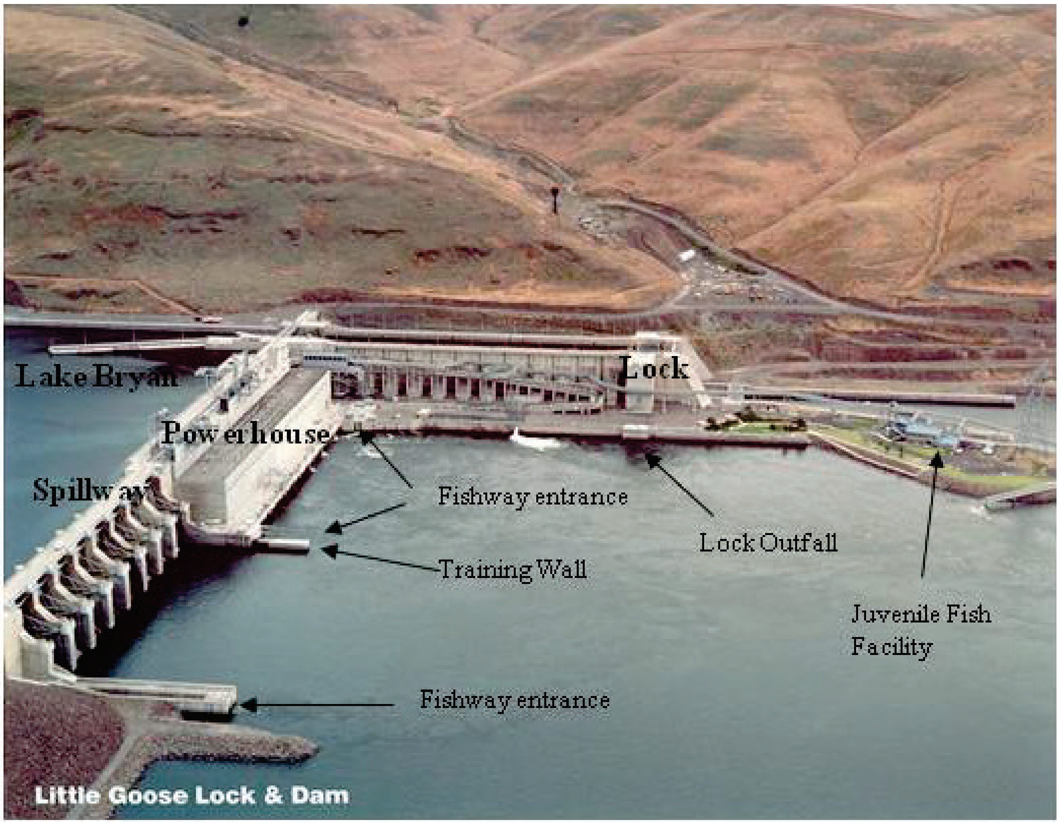
Flow patterns were observed for two deflector designs plus two variations over a wide range of spillway discharge (up to 25 kcfs per spill bay) and tailwater elevations (up to el 547). Of particular interest was the deflector performance for spill bay discharges 4.5 to 10.0 kcfs over tailwater elevations from el 537.0 to el 544.0. Stilling basin and tailrace velocities were also measured for these conditions to assess the potential for tailrace scour and debris transport from the tailrace into the stilling basin. The flow conditions were photographically documented in still photographs and digital video.

Appendix A gives a more detailed accounting of the model study and the experimentation to develop and validate the deflector design for the outside bays at the Little Goose Spillway.

Project description

The Little Goose Dam consists of a powerhouse, spillway and roller-bucket stilling basin, navigation lock, and a non-overflow earthen embankment (Figure 1). The powerhouse has six hydroturbines with a combined discharge capacity of more than 120 kcfs. The 600 ft long navigation lock sits between the powerhouse and south bank. The spillway at Little Goose Dam is 512 ft wide and consists of eight 50 ft wide bays with radial control gates. Flow deflectors have been installed on spill bays 2 through 6 at el 532. The flow deflectors have a length of 12 ft with no transition radius.

Figure 1. Aerial photo of Little Goose Lock and Dam.



The roller-bucket stilling basin at Little Goose Dam shown in Figure 2 is approximately 80 ft long with an invert at el 466.5. The maximum depth in the stilling basin is typically more than 70 ft during normal tailwater conditions. The elevation of the tailwater channel downstream of the stilling basin ranges from 450 to 480 ft.

Model description

A 1:40-scale “section” model of the Little Goose spillway was selected to develop the deflector design. The model consisted of two bays and one half-bay of the Little Goose spillway and nearly 90 ft of the non-overflow portion of the dam. The model reproduced two gates and one half-gate 50 ft wide radial gates, two 14 ft wide piers between gates, the spillway and roller-bucket stilling basin and baffle blocks end sill, and approximately 600 ft of exit channel downstream of the stilling basin (Figures 3 and 4). The spillway, radial gates, stilling basin, baffle blocks, and end sill were fabricated of sheet metal with a painted finish. Piezometers with stilling wells were mounted in the forebay and tailbay for setting pool and tailwater elevations.

Figure 2. Cross section of Little Goose Spillway.

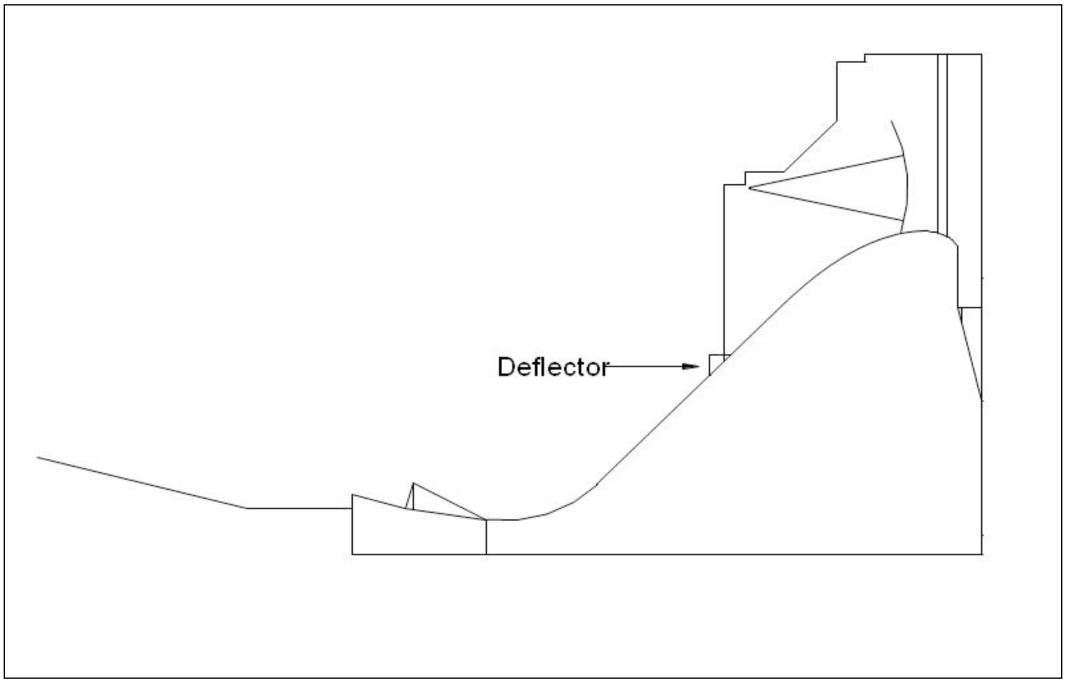


Figure 3. Side view of Little Goose Spillway section model.

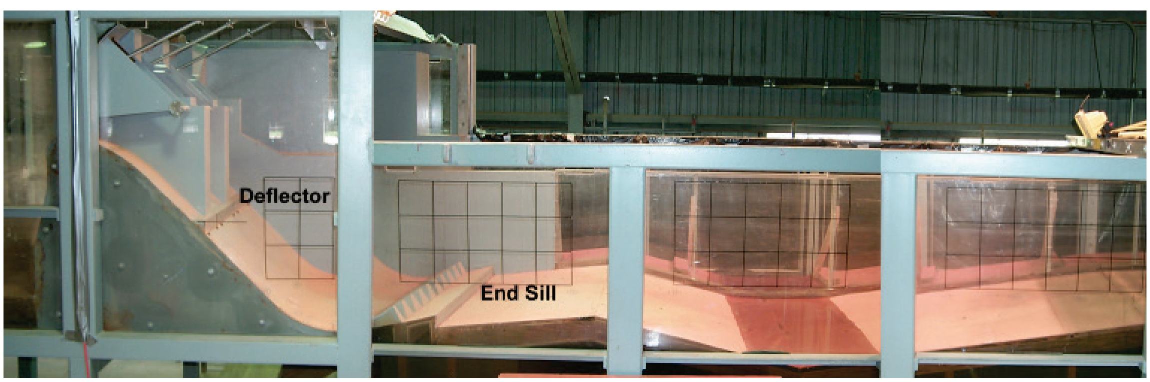
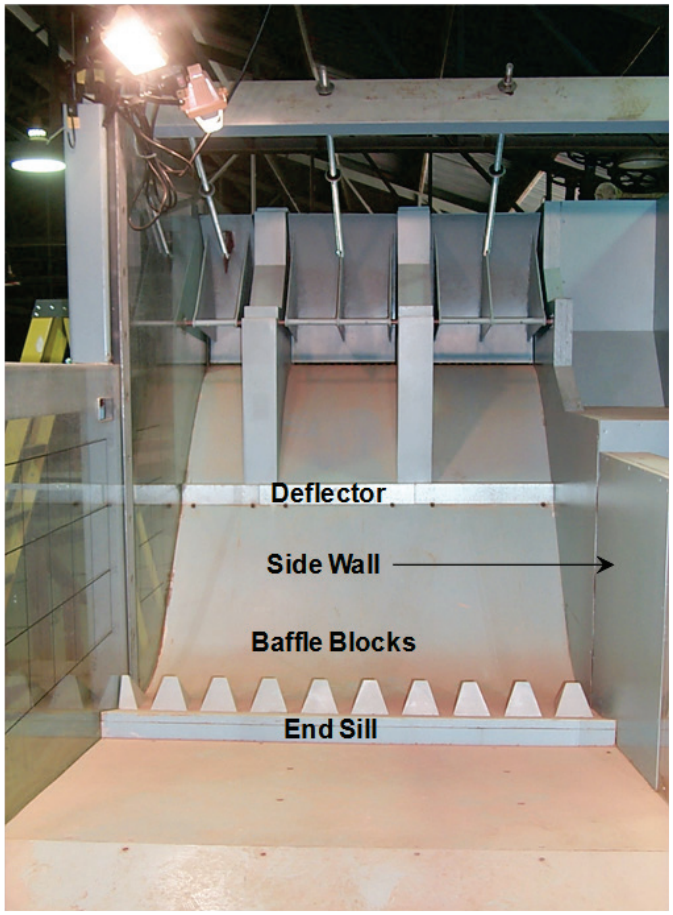


Figure 4. Little Goose Spillway section model view from downstream.



The model was scaled according to Froudian criteria, which results in a set of scaling relationships for converting full-scale dimensions and parameters to model-scale quantities and vice-versa. The relationships are given in Table 1.

Table 1. Scaling relationships.

Dimensional Parameter	Froudian Relationship	Scaling Relationship
Length, L	$L_r=L_m/L_p$	1:40
Time, T	$T_r=T_m/T_p=L_r^{1/2}$	1:6.32
Discharge, Q	$Q_r=Q_m/Q_p=L_r^{5/2}$	1:10,119
Velocity, V	$V_r=V_m/V_p=L_r^{1/2}$	1:6.32

The "r" subscript denotes the parameter model-to-prototype (full-scale) ratio. The "m" and "p" subscript denotes the model and prototype parameter, respectively. The section model was positioned in a 6 ft wide

glass-walled flume to allow observations and photographic documentation of the flow patterns on the spillway and in the stilling basin and tailrace. As such, the model will serve as a flow visualization tool to evaluate vertical and longitudinal flow patterns generated by structural or operational alternatives for various flow rates. Water was supplied to the section model from a large concrete sump by as many as four 12-inch-diameter supply lines. Flow meters on each of the four delivery lines provided a means of setting the model flow rate. The tailwater in the model was controlled with an adjustable sharp-crested weir.

2 Experimental Conditions, Procedures, and Results

Two-dimensional (2D) flow experiments and range of discharge and tailwater elevations

A dividing wall was installed in line with the stilling basin side wall to a distance approximately 450 ft downstream of the end sill to create 2D flow conditions in these tests for the 2.5 spill bays (Figure 5). Flow conditions over the deflectors and through the stilling basin were evaluated for gate openings ranging from 2 ft to 10 ft. With the Little Goose Spillway pool set at el 638.0, for these gate openings, the discharge per spill bay ranged from 4.4 kcfs to 19.6 kcfs (Table 2). Also given in Table 2 is the total spillway discharge assuming eight bays are operating uniformly. This range covered total river flows from approximately 36 kcfs for zero powerhouse flows up to approximately 287 kcfs that includes powerhouse flows of 130 kcfs.

Table 2. Gate openings and corresponding discharges.

Gate Opening	Discharge per spill bay	Discharge for 8 bays*
[ft]	[kcfs]	[kcfs]
2	4.45	35.6
4	7.29	58.3
5	9.71	77.7
6	10.12	81.0
8	14.98	119.8
10	19.58	156.7

*8 bays in uniform operation.

Experimental procedure

For each experiment, a uniform opening was set for all the radial gates, a discharge was set, and the upper pool was stabilized at el 638.0. Tailwater elevation was then adjusted at 2 ft intervals from as low as el 532.0 up to as high as el 547.0. As the tailwater was increased, the flow conditions at the deflector, in the stilling basin, and in the tailrace were observed, classified, and documented with video and photographs. For one skimming flow, velocity profiles were taken at the end sill and at 100, 200, and 300 ft

downstream along the extended centerline of the middle bay. The velocities were taken with a side-looking Acoustic Doppler Velocimeter (ADV) capable of measuring velocity in three dimensions. The water surface elevation was noted at each location, and the first measurement was set at approximately 8–12 ft below the surface. Remaining measurements in each profile were made at 8 ft intervals to near the bottom. Additionally, the downstream extent of the vertical circulation cell under the surface jet was also determined using dye injection as a visualization tool.

Observations and results of experiments

Hydraulic performance of each deflector tested was classified into several categories depending upon the action in the stilling basin. The categories and associated hydraulic action are briefly summarized below but are described in greater detail in Appendix A.

1. Category 1: Plunging flow including vented plunging flow, unstably vented plunging flow, non-vented plunging flow
2. Category 2: Unstable or surging flow
3. Category 3: Skimming flow or surface jet
4. Category 4: Undulating flow or an undulating surface jet
5. Category 5: Ramped surface jet
6. Category 6: Surface jump
7. Category 7: Submerged surface jump

1. Plunging flow includes aerated plunging flow. Occurred when the underside of the surface jet was vented at the downstream end of the deflector; *unstable aerated plunging flow,* which occurred when the underside venting of the surface was inconsistent; and *non-aerated plunging flow,* which occurred when the underside aeration ceased, but there was sufficient momentum to still cause a plunging flow off of the deflector.

2. Unstable or surging flow. Occurred with the flow alternately attempting to ride the surface of the tailwater but then plunging to the stilling basin floor with tailwater surging over the plunging flow.

3. Skimming flow or surface jet. Occurred when the spillway jet remained along the surface of the tailwater with a relatively flat water surface with no plunging action and little downwelling.

4. Undulating flow or an undulating surface jet. Occurred when the spillway jet coming off of the deflector would ride over the downstream water surface forming an undulating surface with standing waves.

5. Ramped surface jet (a refinement of previous classifications). Occurred when the spillway jet coming off of the deflector would "ramp up" steeply on the downstream water surface forming an undulating surface with significant downwelling at the standing waves.

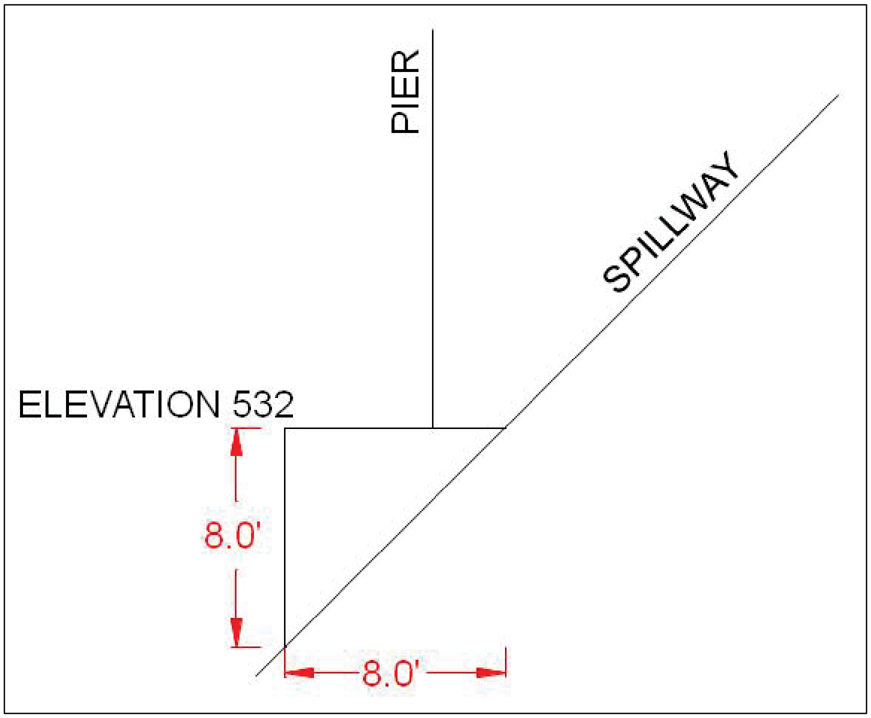
6. Surface jump. Occurred when a hydraulic roller formed at the deflector, resulting in a hydraulic jump that was elevated off the stilling basin floor. This includes an *unstable surface jump*, which occurs when the sloping upstream face of the surface jet attempts to break over into a "surface jump," but retreats and starts again.

7. Submerged surface jump. Occurred when, with higher tailwater, the surface jump was inundated on the deflector, resulting in a submerged hydraulic jump that was elevated off the stilling basin floor.

The best deflector design should provide skimming flow or an undulating surface jet for the widest range of discharges and tailwater elevations. The results of classifying these flow conditions were graphically examined to assess their performance characteristics.

Type I Deflector. With the 8 ft long deflector (Figure 5) at el 532.0 and low tailwater elevations, the spillway jet was classified as plunging flow (Category 1) for even small discharges. For higher discharges (6–10 ft gate openings), the jet plunged to the depth of the stilling basin, transporting air bubbles to the full depth of the stilling basin. In general, this would be expected to be an undesirable condition relative to TDG absorption. As the tailwater was increased, a mildly unstable flow condition developed where the underside of the spillway jet was intermittently vented at the deflector (Category 2).

Figure 5. Type I flow deflector.



With higher tailwater, a skimming flow or surface jet (Category 3) developed for all of the flows tested including the 10 ft gate opening with 19.6 kcfs per bay. This was the most desirable flow condition for dissolved gas since the jet was generally maintained along the surface of the tailwater. With a surface jet, a strong longitudinal circulation cell developed in the stilling basin and extended well downstream into the tailrace. For these experiments, the circulation cell extended as far as 580 ft downstream of the stilling basin end sill.

For higher relative tailwater, an undulating surface jet formed, which was classified in Category 4. For this flow condition, the jet remained essentially on the surface, even though the surface was undulating. Thus, the effects on dissolved gas should be similar to the surface jet.

With additional tailwater depth, the jet began to ramp upward on the tailwater as it left the deflector (Category 5). This flow condition produced turbulence and surface waves that transported dye and air bubbles to the full depth of the tailrace. Because of the relatively high tailwater elevation (deep tailwater) required for this condition, the ramped jet should be avoided if possible. Additional increases in tailwater caused a surface jump to form immediately downstream of the deflector (Category 6). With extremely high tailwater, a submerged jump formed over the deflector,

resulting in a plunging nappe with a submerged roller triggered by the submergence of the deflector (Category 7).

Field observations have indicated that, next to discharge, tailwater depth is the dominant parameter in determining the TDG absorption. Although a significant amount of the energy in the discharge is dissipated in the surface jump, and downstream velocities are significantly reduced, because of the high tailwater required, this condition will likely contribute more to dissolved gas absorption compared to the skimming or undulating surface jets.

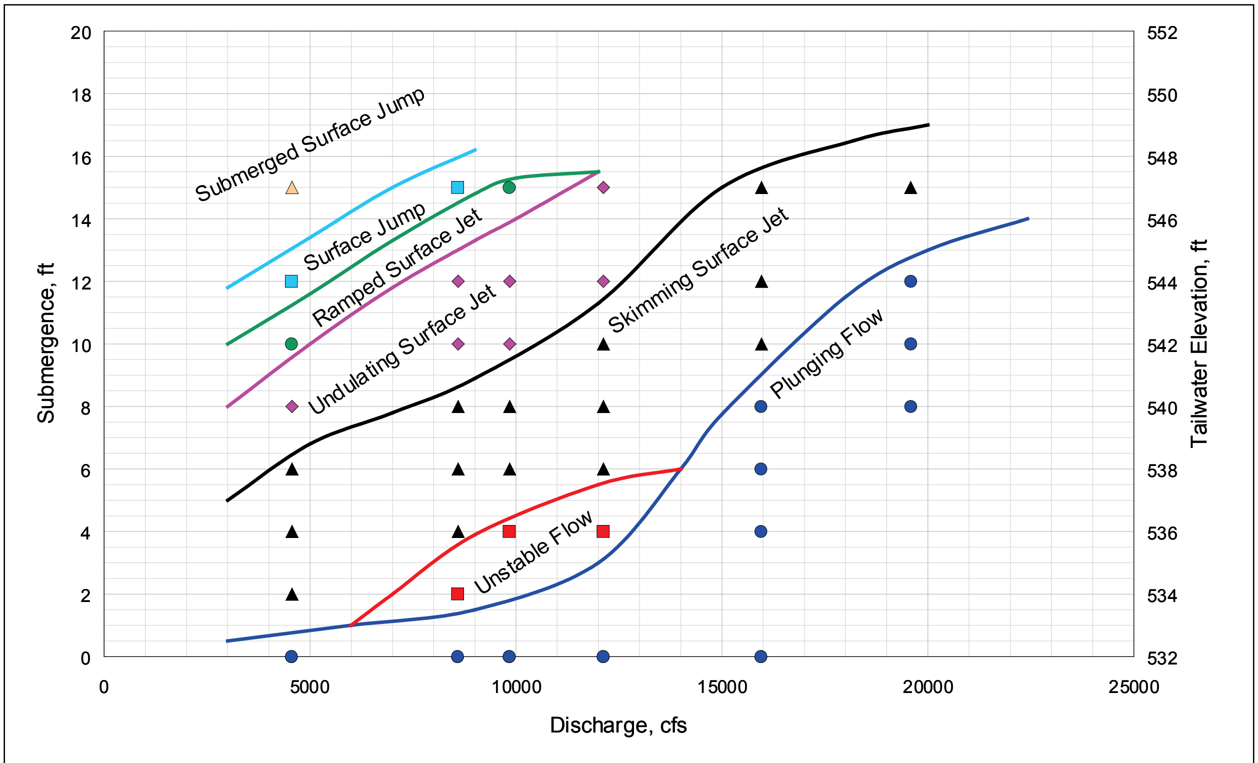
The performance of the Type I deflector is summarized in Figure 6, which shows performance category as a function of deflector submergence and discharge per spill bay. Deflector submergence, S, is defined as

$$S = TW_{el} - Defl_{el} \quad (1)$$

where TW_{el} and $Defl_{el}$ are the tailwater elevation and deflector elevation, respectively. For flows between 7.0 and 10.0 kcfs per spill bay, tailwater could vary by 8–10 ft, while maintaining the recommended skimming or undulating surface jet.

The tailwater range for Little Goose for river discharges from approximately 35 kcfs (~4.5 kcfs/bay) to 286 kcfs (~10.0 kcfs/bay with 130 kcfs powerhouse) is from el 537.0 up to approximately el 544.0. The performance curves in Figure 6 show that skimming and undulating surface jets categories are prevalent for this range of discharges and tailwater elevations. Changing the deflector elevation upward or downward by a couple of feet would shift the performance curves relative to the submergence parameter, while the tailwater range remains the same. For the 7.0 to 10.0 kcfs per spill bay discharge range and the tailwater range, it appears that the Type I Little Goose deflector is likely near its optimum position at el 532.0. This elevation provides surface-jet performance for discharges up to nearly 10.0 kcfs per spill bay.

Figure 6. Type I performance curves.



Type II Deflector. Figure 7 shows the performance of the Type II deflector, which is shown in Figure 8. This deflector design was selected for evaluation because it was a simple lengthening (by 4.0 ft) of the existing Type I deflector. For discharges of 7.0 to 10.0 kcfs per spill bay, a skimming or an undulating surface jet occurred for a tailwater range of approximately 8–10 ft. For river discharges from approximately 35 kcfs to 286 kcfs with associated tailwater elevations at el 537.0 up to approximately el 544.0, the performance curves in Figure 7 show that skimming and undulating surface jet categories are prevalent for this range of discharges and tailwater elevations. The Type II Little Goose deflector is likely near its optimum position at el 532.0 to provide surface-jet performance for discharges up to nearly 10.0 kcfs per spill bay.

Figure 7. Type II performance curves.

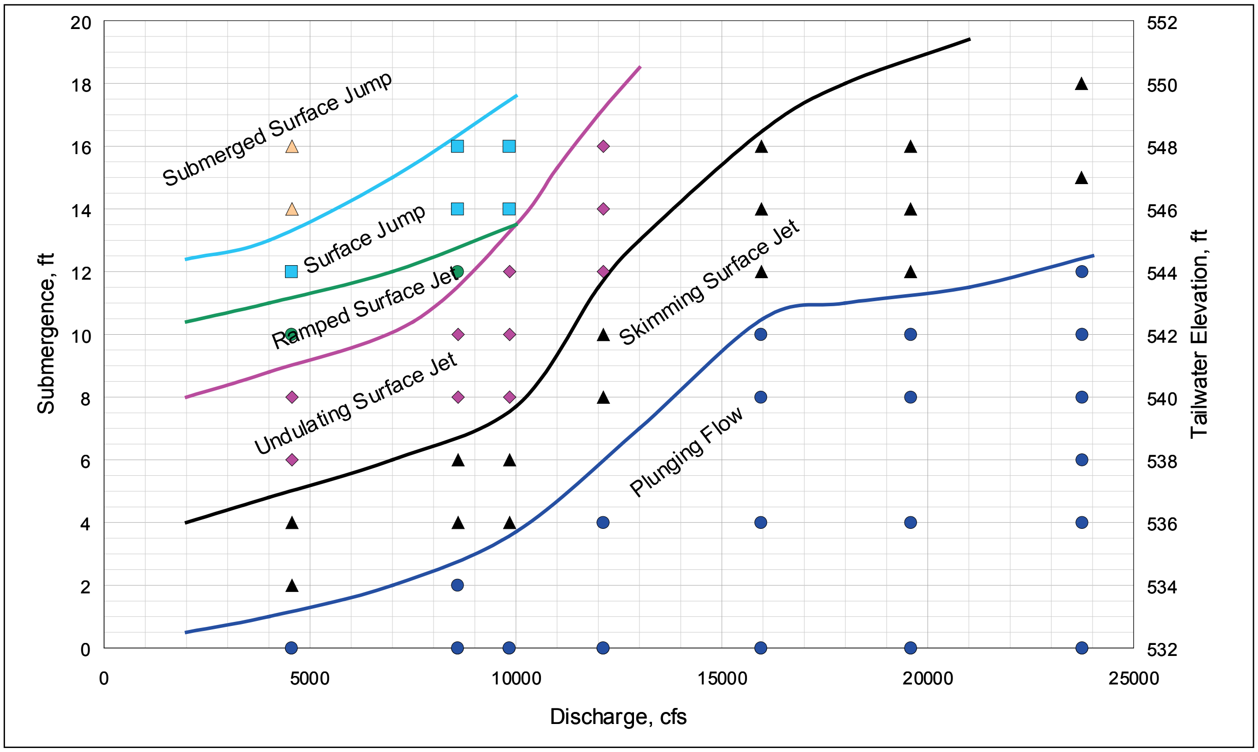
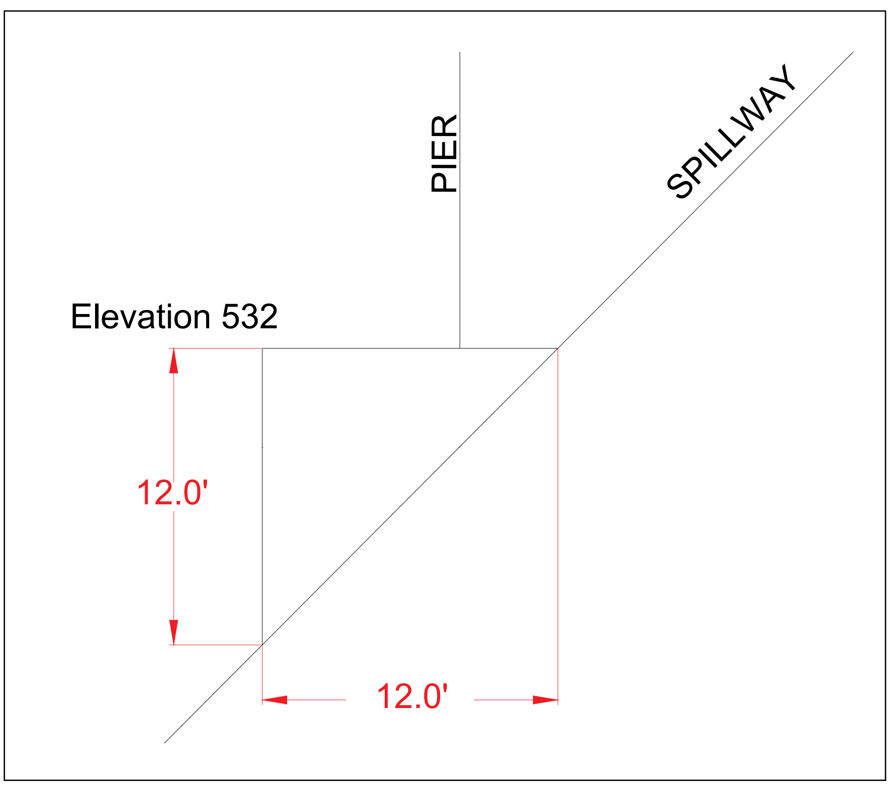


Figure 8. Type II deflector.



Type I-b Deflector. This deflector design (Figure 9) was selected for evaluation because it was an addition of a 10 ft radius transition from the spillway to the Type I deflector. Its performance is shown in Figure 10. For discharges from 7.0 to 10.0 kcfs per bay, a skimming or an undulating surface jet occurred for a tailwater range of approximately 6–7 ft. For a tailwater range from el 537.0 up to approximately el 544.0, the performance curves in Figure 10 show that skimming and undulating surface jet categories are prevalent. On the upper end of these ranges, the operational zone extends slightly into the Ramped Surface Jet Category. For 10.0 kcfs per bay, and a low tailwater, the performance nears the plunging category. Thus, the Type I-b deflector could be lowered by 1 ft to move the "high discharge-low tailwater" operation away from the plunging regime.

Type II-b Deflector. This deflector design (Figure 11) was selected for evaluation because it was typical of the deflector design added to several spillways on the Snake and Columbia Rivers. The performance of the Type II-b deflector is shown in Figure 12. For discharges from 7.0 to 10.0 kcfs per bay, a skimming or an undulating surface jet occurred for a tailwater range of approximately 5–7 ft. For the expected tailwater range of el 537.0 up to approximately el 544.0, the performance curves in Figure 12 show that skimming and undulating surface jet categories are prevalent. However, on the upper end of these ranges, the operational zone extends significantly into the Ramped Surface Jet Category. Although the Ramped Surface Jet Category reduces the plunging action compared to the Plunging Jet Category, the high standing waves tend to contribute to plunging action on their downstream sides. Additionally, for 10.0 kcfs per bay, and a low tailwater, the performance nears the plunging category. Thus, the operational characteristics of the Type II-b deflector extend too far into the Ramped Surface Jet regime and are uncomfortably close to the plunging regime.

Vertical velocity profiles were taken in the tailrace at points along the centerline of the model to determine the downstream extent of the circulation cell under the deflected jet. The measurements show velocities in the upstream direction along the tailrace channel ranging from as low as 2 ft/sec to as high as 17 ft/sec. The highest velocities occurred, not surprisingly, for the higher discharges. The extent of the circulation cell appears to approach the maximum extent for performance categories 3 (skimming flow) and higher, which is reasonable since plunging flow should reattach to the tailrace channel sooner than surface flows. The circulation cell also seems to approach its maximum size with a discharge of approximately 10.0 kcfs per spill bay.

Figure 9. Type I-b deflector.

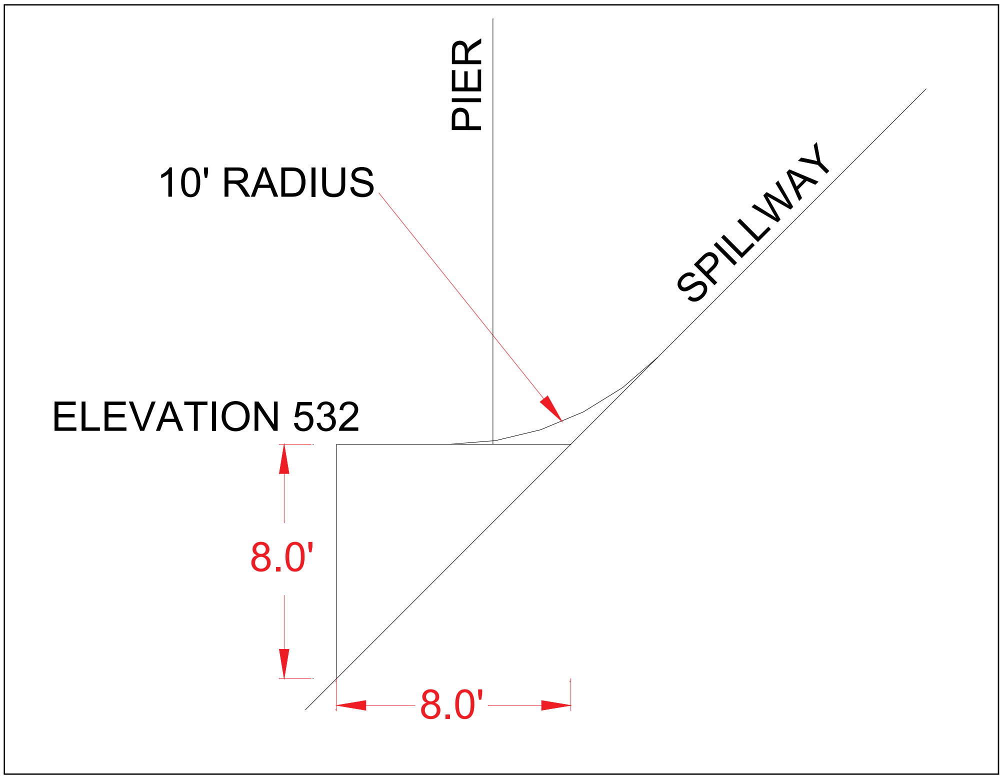


Figure 10. Type I-b performance curves.

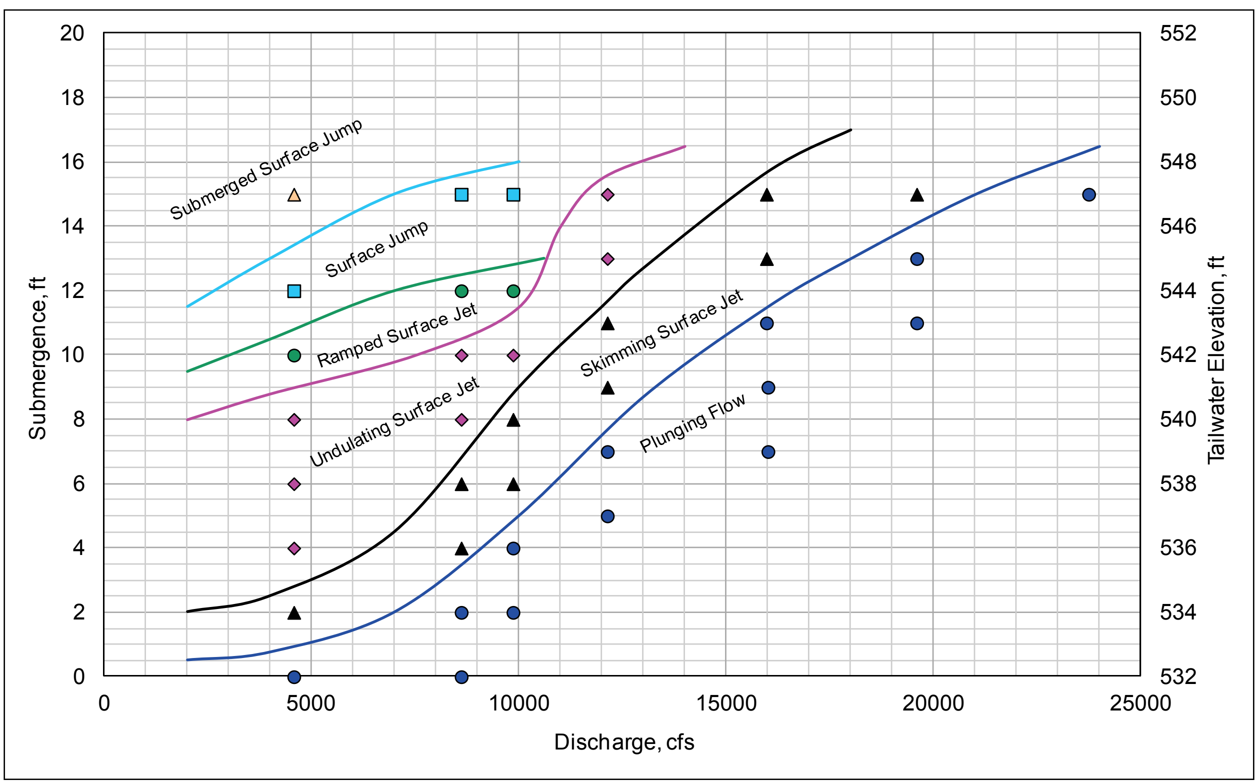


Figure 11. Type II-b deflector.

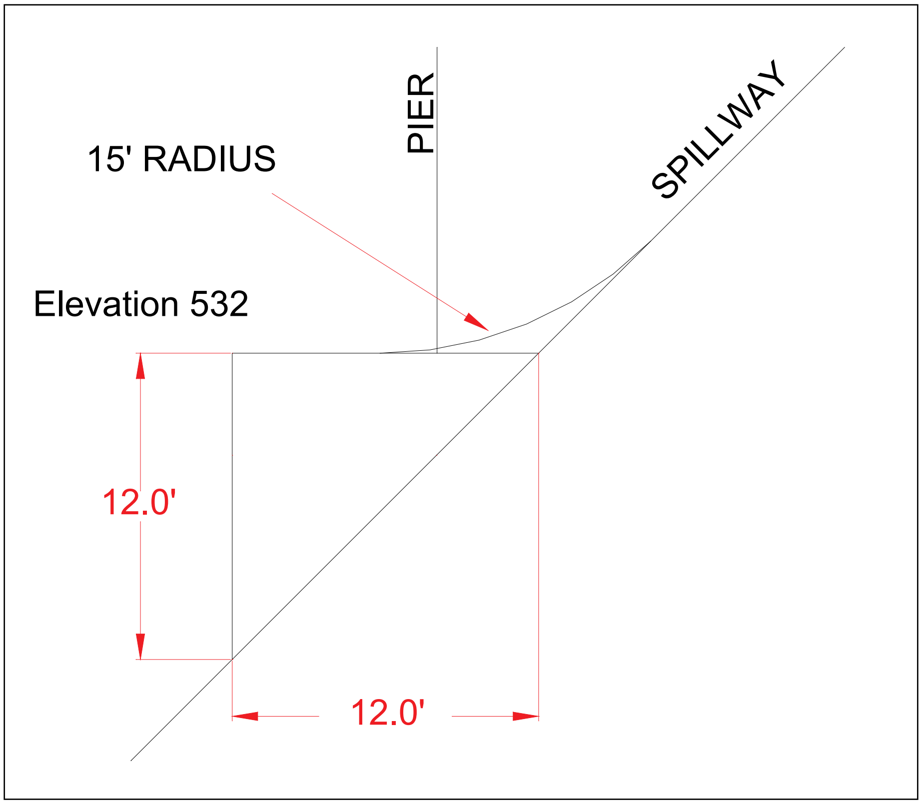
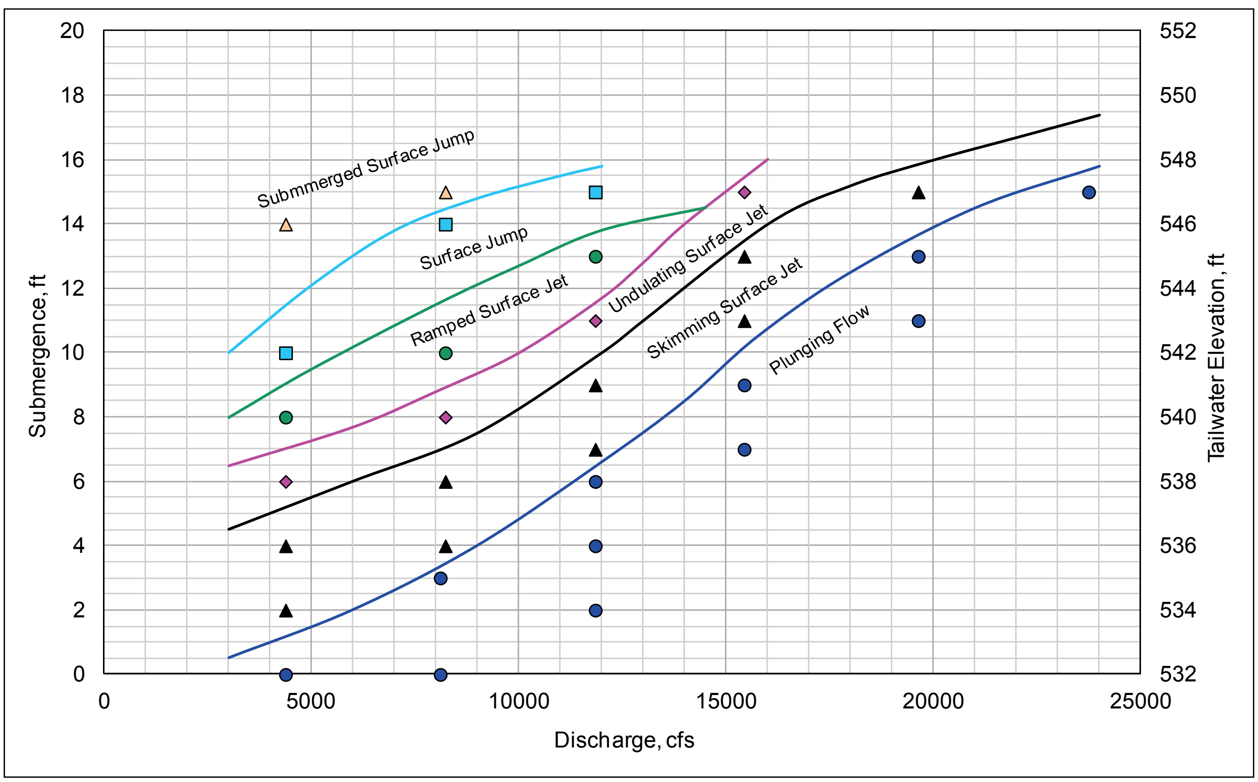


Figure 12. Type II-b performance curves.



Comparison of performance characteristics

Figure 13 shows a comparison between the performance of the existing 8 ft Type I deflector and the 12 ft Type II deflector. For a design discharge range up to 10.0 kcfs/bay, the Type II deflector does not provide an increase in the range of tailwater over which skimming/undulating surface jet performance occurs. Figure 14 shows a comparison between the performance of the existing Type I deflector and the Type I-b deflector. With a similar comparison, the addition of a transition radius does not appear to contribute to improving the range over which skimming flows occur. Likewise, Figure 15 shows the performance of the Type I and the Type II-b deflectors. Clearly, the range of skimming and undulating surface flows is larger over the design discharge range for the existing Type I deflector.

Figure 13. Comparison of the performance characteristics of Type I and Type II deflectors.

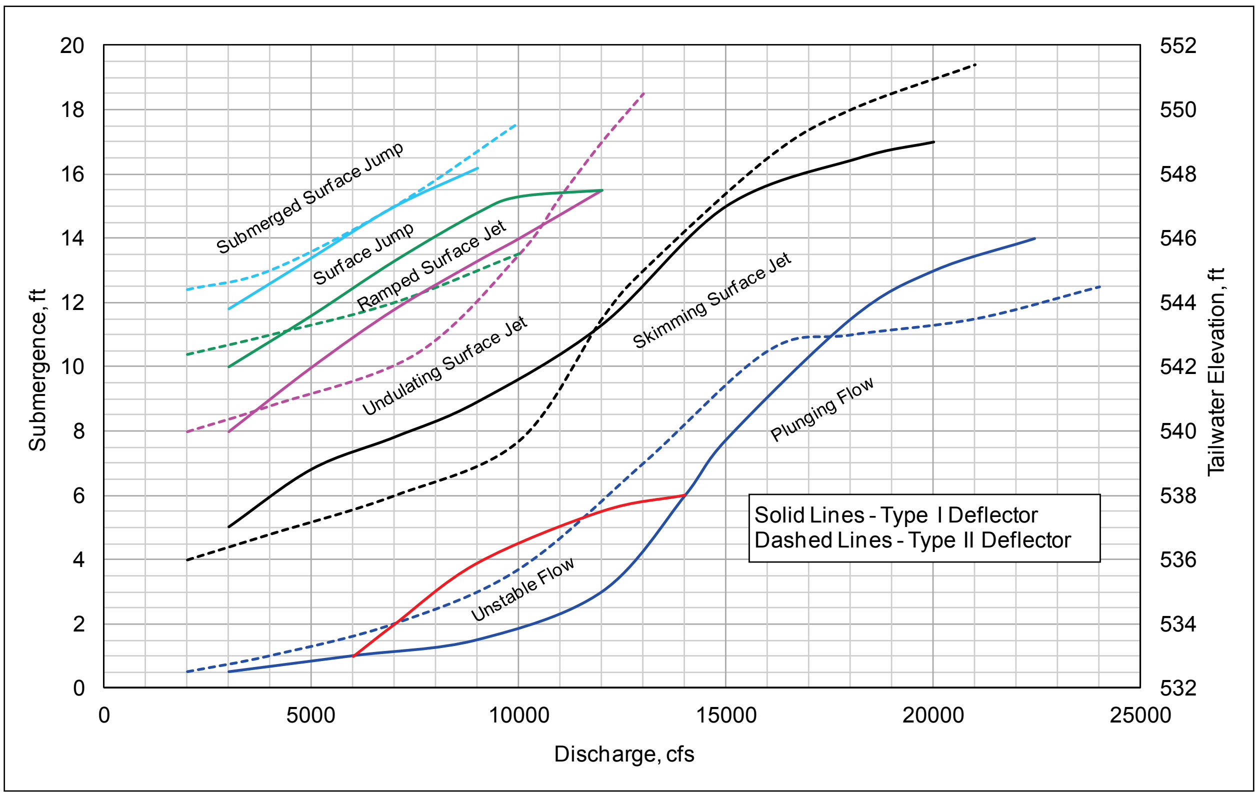


Figure 14. Comparison of the performance characteristics of Type I and Type I-b deflectors.

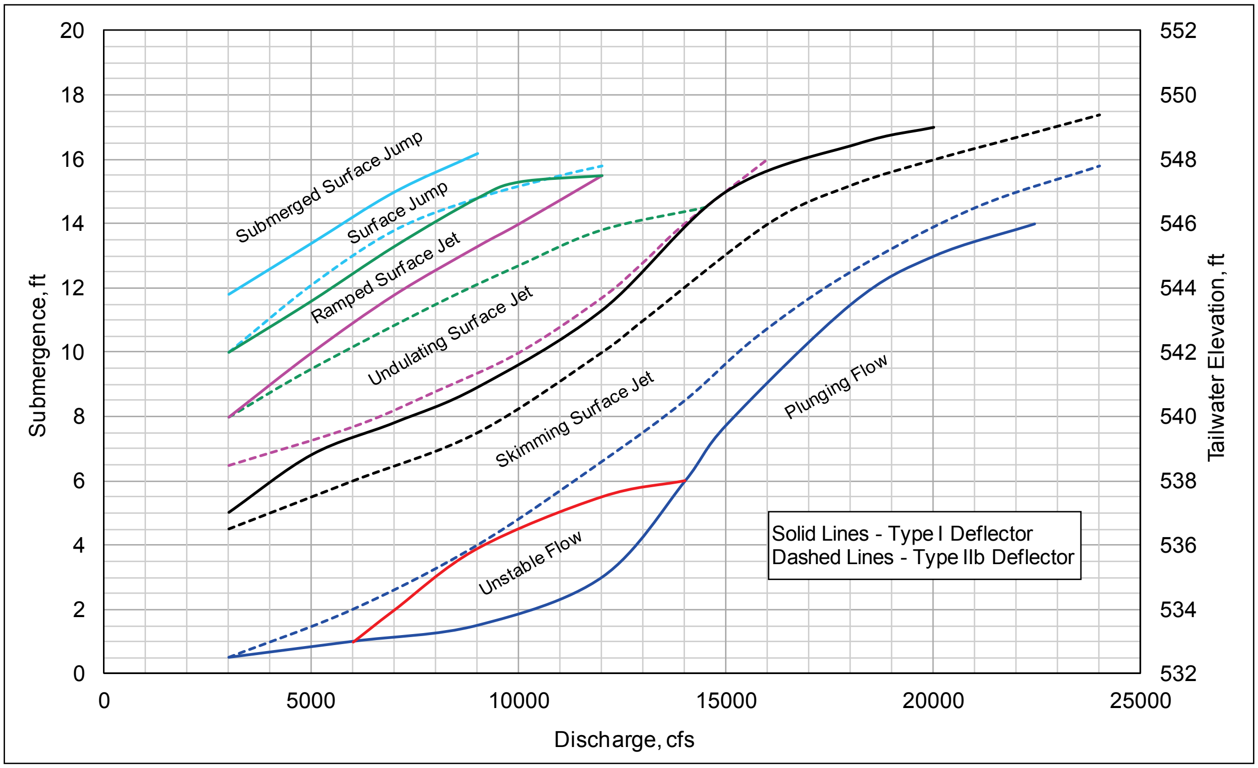
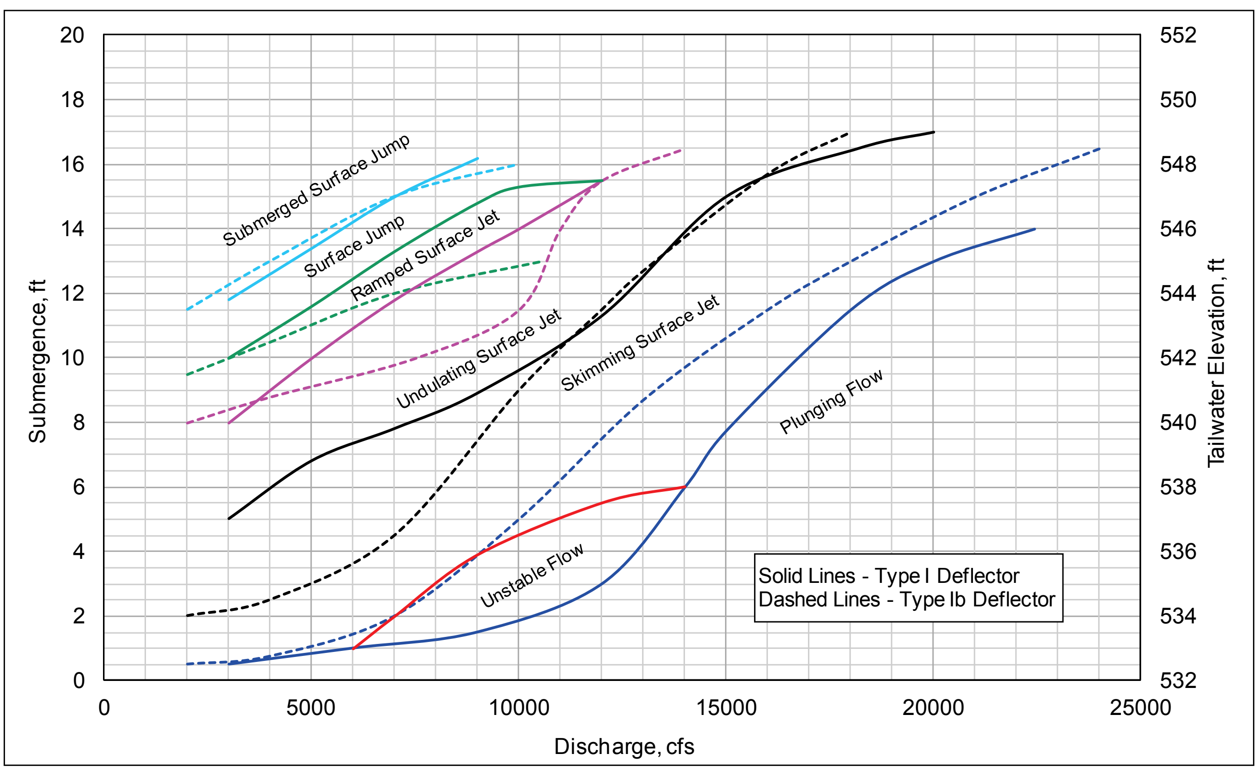


Figure 15. Comparison of the performance characteristics of Type I and Type II-b deflectors.



3 Conclusions and Recommendations

Based on the results of this study and the comparison of the performance characteristics of the four deflectors, the existing Type I deflector at el 532.0 is recommended for the exterior bays at Little Goose Spillway. There was essentially no difference in the performance character of the Type I deflector and the Type II deflector over the design discharge range of 7.0–10.0 kcfs per spill bay. Thus, a Type II deflector at el 532.0 will likely perform as well as the Type I. The Type I-b and Type II-b deflectors demonstrated a narrower range of tailwater elevations for a skimming and undulating surface jet. The Type I-b and Type II-b are not recommended based on their performance characteristics.

Velocities, as high as 17 ft/sec, were measured along the tailrace channel bottom. The highest velocities were located along the channel bottom between the end sill and 100 ft downstream of the end sill. Based on the potential for transport of material, the authors recommend that a close check be kept on the possibility of erosion in the stilling basin or immediate tailrace. Detailed hydrographic survey data should be taken in the stilling basin and tailrace to assess changes in bathymetry caused by scour or ball-mill grinding.

Appendix A: Memorandum for Record Subject: Little Goose Spillway Section Model, Deflector Evaluation Report, Dated 25 January 2002

PREFACE

This document contains figures that are linked to the referencing text through hypertext links. The hypertext links are indicated by blue text and are activated with a single click of the left mouse button near the highlighted word. The large left facing arrow (go to previous view icon) on the toolbar will return the display to the document. Appendices D, E, and F are Microsoft Excel Files. This document also contains two video clips of model flow conditions. The file names of these clips are “lgso12final.avi” and “lgso38final.avi.” The Excel files and video files must be located in the same directory as the Adobe pdf document for proper playback and can be viewed on a computer that has the QuickTime viewer installed. The videos are activated with a single click of the left mouse button on the blue text and then a single click of the left mouse button over the video clip page.

CEERD-HC-IE 25 January 2002

MEMORANDUM FOR RECORD

SUBJECT: The Little Goose Spillway Section Model, Deflector Evaluation Report

1. This data report summarizes the results from experiments conducted on the Little Goose Section Model as defined in Task I in the scope of work presented in Appendix A. The observations presented in the following paragraphs represent our investigation into the performance of the 4 alternative deflector designs, as follows:

a. Existing spillway deflector (Type I)
b. Type I deflector with a 4-ft extension (Type II)
c. Type I with a 10-ft transition radius (Type Ib)
d. Type II with a 15-ft transition radius (Type IIb)

All of these deflectors were located at elevation[1] 532.0. The Type I (original design) is an 8-ft long deflector without a transition radius and is shown in Figure 1. The Type Ib deflector is an 8-ft long deflector with a 10-ft transition radius from the spillway face to the deflector (Figure 2). The Type II (Figure 3) is 12 ft long without a transition radius, while the Type IIb (Figure 4) has a 15-ft transition radius. The classification of the stilling basin and tailrace flow conditions based on hydraulic action, photographs to document the flow patterns and other observations are presented in this data report.

Background

2. The 1:40-scale section model of Little Goose reproduces approximately 600 ft of approach, 2-1/2 50-ft-wide gate bays, two 14-ft-wide piers, tainter gates, the spillway, the roller bucket stilling basin, baffle blocks, end sill, and about 100 ft of the non-overflow section and powerhouse on the south end of the spillway (Figure 5). About 600 ft of exit channel is reproduced (Figure 6). The spillway, tainter gates, stilling basin, baffle blocks, and end sill were fabricated of sheet metal with a painted finish. Piezometers with stilling wells were mounted in the forebay and tailbay for setting pool and tailwater elevations.

Experimental Conditions and Procedures

3. A dividing wall was installed in line with the stilling basin wall to a distance approximately 450 ft downstream of the end sill to create 2-dimensional model flow conditions in these tests. Flow conditions over the deflectors and through the stilling basin were evaluated for gate openings ranging from 2 ft to 10 ft. With the Little Goose pool elevation set at el 638.0, for these gate openings, the discharge per spillbay ranged from 4.4 kcfs to 19.6 kcfs (Table 1). Also given in Table 1 is the total spillway discharge assuming 8 bays are operating uniformly. This range covered total river

[1] Elevations herein are given in feet referenced to the National Geodetic Vertical Datum (NGVD).

flows from about 36 kcfs for zero powerhouse flows up to about 287 kcfs that includes powerhouse flows of 130 kcfs.

Table 1. Gate Openings and Corresponding Discharges

Gate Opening	Discharge per spillbay	Discharge for 8 bays
[ft]	[kcfs]	[kcfs]
2	4.45	35.6
4	7.29	58.3
5	9.71	77.7
6	10.12	81.0
8	14.98	119.8
10	19.58	156.7
*8 Bays in Uniform Operation		

4. For each experiment, a discharge was set and the upper pool was stabilized at el 638.0. Tailwater elevation was then adjusted at 2-ft intervals from as low as el 532.0 up to as high as el 547.0. As the tailwater was increased, the flow conditions at the deflector, in the stilling basin, and in the tailrace were observed, classified, and documented with video and photographs. For one skimming flow, velocity profiles were taken at the end sill and at 100-, 200-, and 300-ft downstream along the extended centerline of the middle bay. The velocities were taken with a side-looking Acoustic Doppler Velocimeter (ADV) capable of measuring velocity in 3 dimensions. The water surface elevation was noted at each location and the first measurement was set at approximately 8-12 ft below the surface. Remaining measurements in each profile were made at 8 ft intervals to near the bottom.

To help understand the effects of lateral entrainment of powerhouse flows, the thickness of the surface jet without lateral entrainment in these experiments was determined. The thickness of the surface jet was measured at the same locations as the velocity profiles and at 100 ft upstream of the end sill for skimming and undulating surface jet conditions. The jet thickness measurements will be compared to similar measurements in the section model, when lateral flow is introduced through the flume sidewall. This will simulate the entrainment of powerhouse releases into spill flows to indicate the effects of lateral entrainment on the thickness or plunging character of the surface jet.

The downstream extent of the vertical circulation cell under the surface jet was also determined using dye injection as a visualization tool. For surface jets, the lift angle of

the jet off of the deflector was measured, as recommended by Dr. Larry Weber[2] of the Iowa Institute of Hydraulic Research, to help qualify the performance categories discussed in the next section.

Results

5. In previous studies of deflectors (USAEWES 1996a, USAEWES 1996b, USAEWES 1999), hydraulic performance was classified into several categories depending upon the action in the stilling basin. Similar categories with only slight modification were adopted to describe the performance of Little Goose Type I deflector. The categories, given below, and associated hydraulic action are described in detail in Appendix B.

a. Category 1: Plunging flow including vented plunging flow, unstably vented plunging flow, non-vented plunging flow.
b. Category 2: Unstable or surging flow.
c. Category 3: Skimming flow or surface jet.
d. Category 4: Undulating flow or an undulating surface jet.
e. Category 5: Ramped surface jet.
f. Category 6: Surface jump.
g. Category 7: Submerged surface jump

7. With the deflector at el 532.0, at low tailwater elevations for even small discharges, the spillway jet was classified as plunging flow (Category 1). Although the jet trajectory angled downward after leaving the deflector, for low discharge (2-4 ft gate openings), the deflected jet stayed near the tailwater surface (Figure 7). For higher discharges (6-10 ft gate openings), the jet plunged to the depth of the stilling basin (Figure 8). This plunging condition would transport air to the full depth of the stilling basin. In general, we would expect this to be an undesirable condition relative to total dissolved gas absorption. As the tailwater was increased, a mildly unstable flow condition developed where the underside of the spillway jet was intermittently vented at the deflector.

8. With higher tailwater, a skimming flow or surface jet (Category 3) developed for all of the flows tested including the 10 ft gate opening with 19.6 kcfs per bay (Video 1, Video 2). With a lift angle of up to about 5 degrees off the horizontal, this was the most desirable flow condition for dissolved gas, since the jet was generally maintained along the surface of the tailwater. With a surface jet, a strong longitudinal circulation cell developed in the stilling basin and extended well downstream into the tailrace. For

[2] Discussion with Dr. Larry Weber, Iowa Institute of Hydraulic Research, on Wanapum Spillway Study.

these experiments, the circulation cell extended as far as 580 ft downstream of the stilling basin end sill.

9. For higher relative tailwater, an undulating surface jet formed (Figure 9), which was classified in Category 4. The lift angle for an undulating surface jet varied over a range from about 5 degrees up to 20 degrees. For this flow condition, the jet remained essentially on the surface, even though the surface was undulating. Thus, the effects on dissolved gas should be similar to the surface jet.

10. With additional tailwater, the jet began to “ramp” upward on the tailwater as it left the deflector (Category 5) with a lift angle greater than 20 degrees (Figure 10). This flow condition produced turbulence and surface waves that transported dye and air bubbles to the full depth of the tailrace. Furthermore, the ramped jet required a relatively high tailwater elevation. Additional increases in tailwater caused a surface jump to form immediately downstream of the deflector (Figure 11). With extremely high tailwater, a submerged jump formed over the deflector, resulting in a plunging nappe with a submerged roller triggered by the submergence of the deflector (Figure 12).

11. Field observations have indicated that, next to discharge, tailwater depth is the dominant parameter in determining the total dissolved gas absorption (Schneider and Wilhelms 1998). Although a significant amount of the energy in the discharge is dissipated in the surface jump, and downstream velocities are significantly reduced, because of the high tailwater required, this condition may contribute more to dissolved gas production. Appendix C is a photo album of flow conditions.

12. The performance of the Little Goose spillway deflectors was analyzed based on a submergence parameter[4] and discharge per spill bay. While each deflector alternative is discussed separately, all of the observations are presented in Appendix D.

13. Type I Deflector. The performance of the Type I deflector is shown in Figure 13. For flows between 7.0 and 10.0 kcfs per spill bay[5], tailwater could vary by 8-10 ft, while maintaining a skimming or undulating surface jet. A surface jet is our recommended performance category to help minimize potential plunging action and the resulting dissolved gas levels. The tailwater range for Little Goose for river discharges from about 35 kcfs (~4.5 kcfs/bay) to 286 kcfs (~10.0 kcfs/bay with 130 kcfs powerhouse) is

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[4]Deflector submergence was defined as the difference between tailwater elevation and deflector elevation. Thus, with a tailwater at el 538.0, the submergence of the deflector was 6.0.

[5] Likely maximum spill to avoid exceeding 120 percent TDG, based on field studies of TDG exchange.

from el 537.0 up to about el 544.0. The performance curves in Figure 13 show that skimming and undulating surface jets categories are prevalent for this range of discharges and tailwater elevations. Thus, it appears that the Type I Little Goose deflector is likely near its optimum position at el 532.0 to provide surface-jet performance for discharges up to nearly 10.0 kcfs per spill bay.

14. Velocity measurements are tabulated and plotted in Appendix E. No velocity is given for some positions where the air bubble concentration was high, because the high bubble concentration interferes with the measurement capabilities of the ADV probe. For cases where measurements were made in aerated water, the resulting velocity was lower than the actual (Preslan, 2002). Mean velocity was computed, where at least 50 percent of the measured velocity data were deemed "good" based on the signal-to-noise ratio from the instrument. The measurements show velocities in the upstream direction along the tailrace channel ranging from as low as 2 ft/sec to as high as 15 ft/sec. The jet thickness measurements are tabulated in Appendix F. Figure 14 shows the downstream extent of the circulation cell as a function of the performance classification and discharge per spill bay. The extent of the circulation cell appears to approach the maximum extent for performance categories 3 (skimming flow) and higher, which is reasonable, since plunging flow should reattach to the tailrace channel sooner than surface flows. The circulation cell also seems to approach its maximum size with a discharge of about 10.0 kcfs per spill bay.

15. <u>Type II Deflector.</u> The performance of the Type II deflector is shown in Figure 15. This deflector design was selected for evaluation because it was a simple lengthening (by 4.0 ft) of the existing Type I deflector. For discharges of 7.0 to 10.0 kcfs per spill bay, a skimming or an undulating surface jet occurred for a tailwater range of about 8-10 ft. For river discharges from about 35 kcfs to 286 kcfs with associated tailwater elevations at el 537.0 up to about el 544.0, the performance curves in Figure 15 show that skimming and undulating surface jet categories are prevalent for this range of discharges and tailwater elevations. The Type II Little Goose deflector is likely near its optimum position at el 532.0 to provide surface-jet performance for discharges up to nearly 10.0 kcfs per spill bay.

17. Velocity measurements are tabulated and plotted in Appendix E. The measurements show velocities along the tailrace channel ranging from about 15 ft/sec to as low as 2 ft/sec. The jet thickness measurements are tabulated in Appendix F. Figure 16 shows the downstream extent of the circulation cell as a function of the performance classification and discharge per spill bay. The extent of the circulation cell appears to approach the maximum extent for performance categories 3 (skimming flow)

and higher, which is reasonable, since plunging flow should reattach to the tailrace channel sooner than surface flows. The circulation cell also seems to approach its maximum size with a discharge of about 10.0 kcfs per spill bay.

18. Type Ib Deflector. This deflector design was selected for evaluation because it was an addition of a 10-ft radius transition from the spillway to the Type I deflector. Its performance is shown in Figure 17. For discharges from 7.0 to 10.0 kcfs per bay, a skimming or an undulating surface jet occurred for a tailwater range of about 6-7 ft. For a tailwater range from el 537.0 up to about el 544.0, the performance curves in Figure 17 show that skimming and undulating surface jet categories are prevalent. On the upper end of these ranges, the operational zone extends slightly into the Ramped Surface Jet Category. For 10.0 kcfs per bay, and a low tailwater, the performance nears the plunging category. Thus, the Type Ib deflector could be lowered by 1 ft to move the “high discharge-low tailwater” operation away from the plunging regime.

19. Velocity measurements are tabulated and plotted in Appendix E. The measurements show velocities along the tailrace channel ranging from about 14 ft/sec to as low as 1 ft/sec. The jet thickness measurements are tabulated in Appendix F. Figure 18 shows the downstream extent of the circulation cell as a function of the performance classification and discharge per spill bay. The extent of the circulation cell appears to approach the maximum extent for performance categories 3 (skimming flow) and higher, which is reasonable, since plunging flow should reattach to the tailrace channel sooner than surface flows. The circulation cell also seems to approach its maximum size with a discharge of about 10.0 kcfs per spill bay.

20. Type IIb Deflector. This deflector design was selected for evaluation because it was typical of the deflector design added to several spillways on the Snake and Columbia Rivers. The performance of the Type IIb deflector is shown in Figure 19. For discharges from 7.0 to 10.0 kcfs per bay, a skimming or an undulating surface jet occurred for a tailwater range of about 5-7 ft. For the expected tailwater range of el 537.0 up to about el 544.0, the performance curves in Figure 19 show that skimming and undulating surface jet categories are prevalent. However, on the upper end of these ranges, the operational zone extends significantly into the Ramped Surface Jet Category. Although the Ramped Surface Jet Category reduces the plunging action compared to the Plunging Jet Category, the high standing waves tend to contribute to plunging action on their downstream sides. Additionally, for 10.0 kcfs per bay, and a low tailwater, the performance nears the plunging category. Thus, the operational

characteristics of the Type IIb deflector extend too far into the Ramped Surface Jet regime and are uncomfortably close to the plunging regime.

21. Velocity measurements are tabulated and plotted in Appendix E. The measurements show velocities along the tailrace channel ranging from about 17 ft/sec to as low as 4 ft/sec. The jet thickness measurements are also tabulated in Appendix F. Figure 20 shows the downstream extent of the circulation cell as a function of the performance classification and discharge per spill bay. The extent of the circulation cell appears to approach the maximum extent for performance categories 3 (skimming flow) and higher, which is reasonable, since plunging flow should reattach to the tailrace channel sooner than surface flows. The circulation cell also seems to approach its maximum size with a discharge of about 10.0 kcfs per spill bay.

22. Comparison of Performance Characteristics. Figure 21 shows a comparison between the performance of the existing 8-ft Type I deflector and the 12-ft Type II deflector. Based on a design discharge range of up to 10.0 kcfs/bay, the Type II deflector does not provide an increase in the range of tailwater over which skimming/undulating surface jet performance occurs. Figure 22 shows a comparison between the performance of the existing Type I deflector and the Type Ib deflector. With a similar comparison, the addition of a transition radius does not appear to contribute to improving the range over which skimming flows occur. Likewise, Figure 23 shows the performance of the Type I and the Type IIb deflectors. Clearly, the range of skimming and undulating surface flows is larger over the design discharge range for the existing Type I deflector. Thus, between these alternatives, for maintaining a surface flow, we recommend the existing 8-ft Type I deflector design at el 532.0.

23. The velocity profile measurements showed velocities in the upstream direction along the channel bottom as high as 17 ft/sec. The highest velocities occurred, not surprisingly, for the higher discharges. The highest velocities were located along the channel bottom between the end sill and 100 ft downstream of the end sill. Based on the potential for transport of material, we recommend that a close check be kept on the possibility of erosion in the stilling basin or immediate tailrace. Detailed hydrographic survey data should be taken in the stilling basin and tailrace to assess changes in bathymetry caused by scour or ball-mill grinding.

24. Conclusions and Recommendations. Based on the results of this study and the comparison of the performance characteristics of the four deflectors, the existing Type I deflector at el 532.0 is recommended for the exterior bays at Little Goose Spillway. There was essentially no difference in the performance character of the Type I deflector and the Type II deflector over the design discharge range of 7.0-10.0 kcfs per spill bay.

Thus, a Type II deflector at el 532.0 will likely perform as well as the Type I. The Type Ib and Type IIb deflectors demonstrated a narrower range of tailwater elevations for a skimming and undulating surface jet. The Type Ib and Type IIb are not recommended, based on their performance characteristics. For the discharges tested, velocities as high as 17 ft/sec were measured along the tailrace channel bottom. We recommend that a close check be kept on the possibility of erosion in the stilling basin or immediate tailrace. Detailed hydrographic survey data should be taken in the stilling basin and tailrace to assess changes in bathymetry caused by scour or ball-mill grinding.

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Inland Hydraulic Structures Branch

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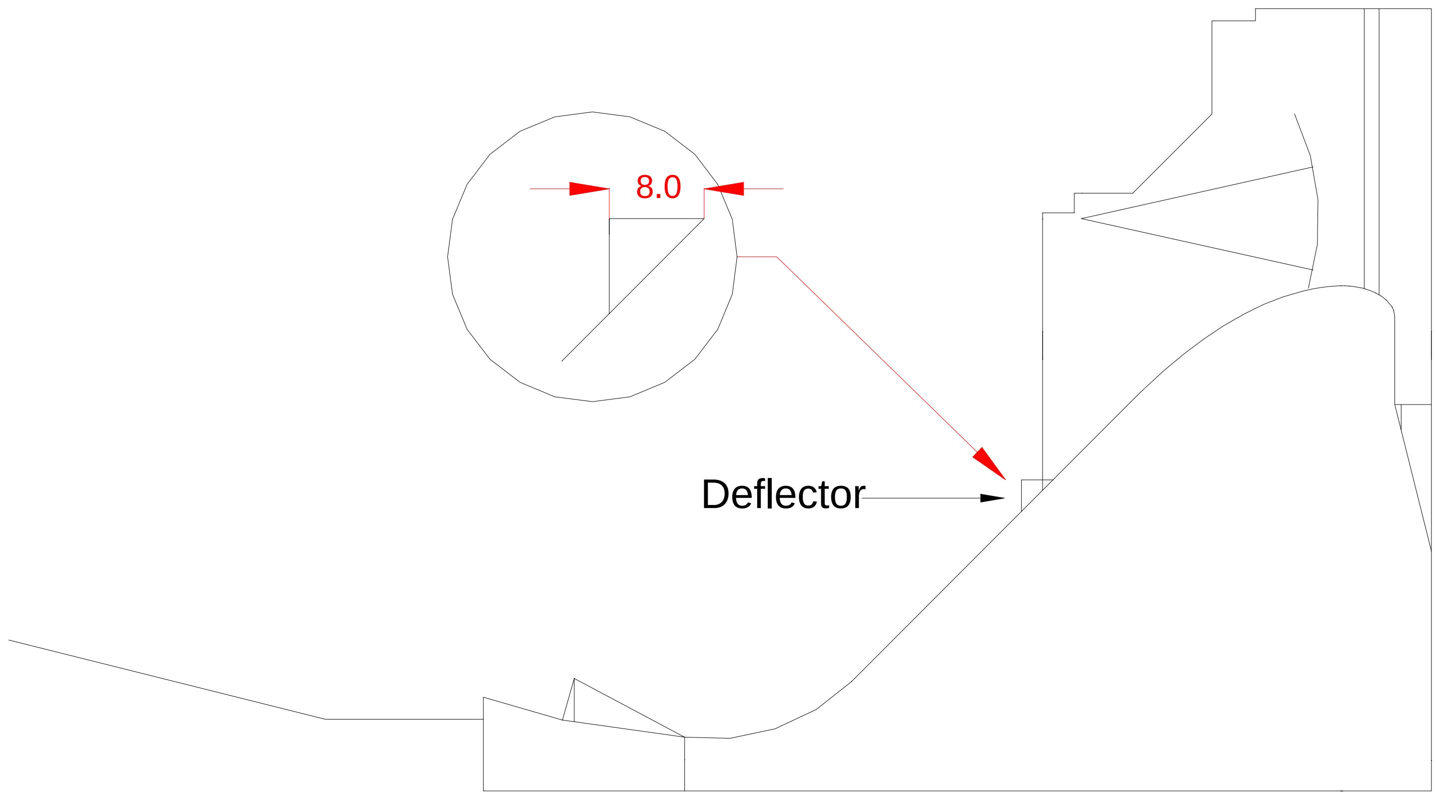


Figure 1. Little Goose Section Model with Type I Flow Deflector, Elevation View

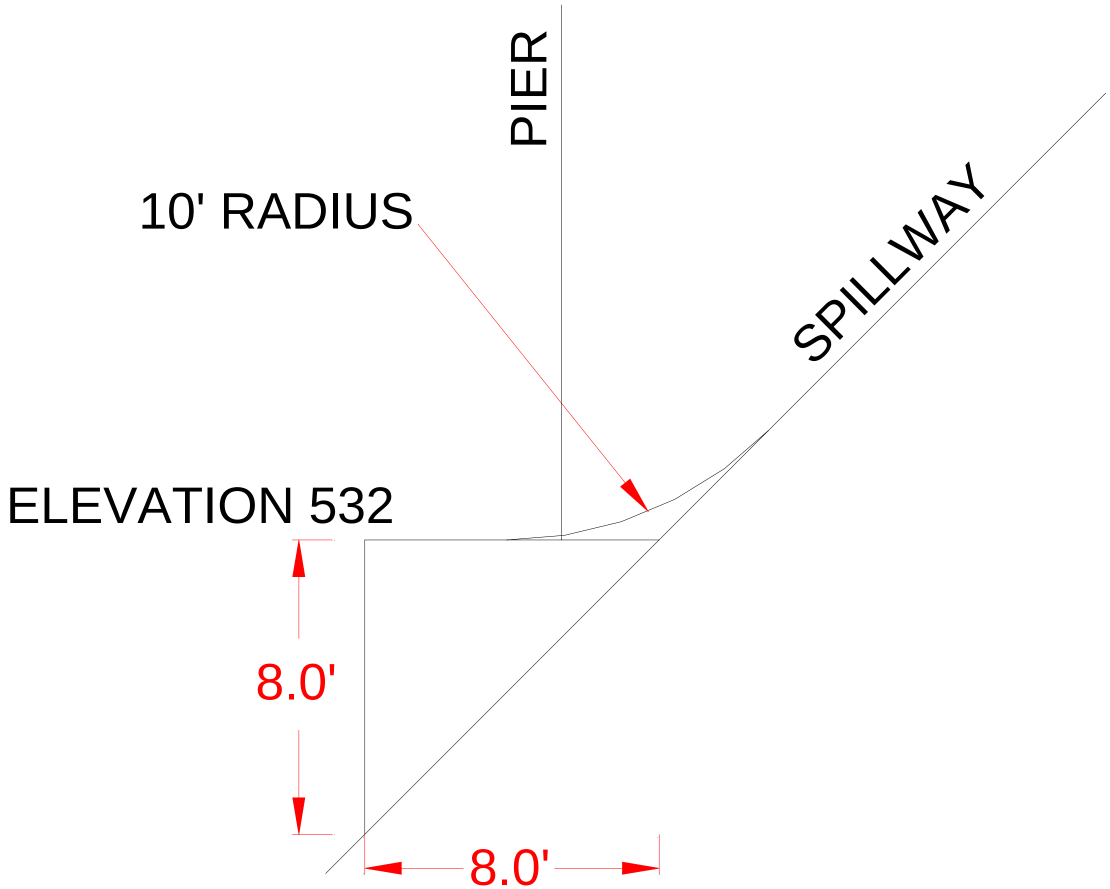


Figure 2. Little Goose Section Model Type Ib Flow Deflector

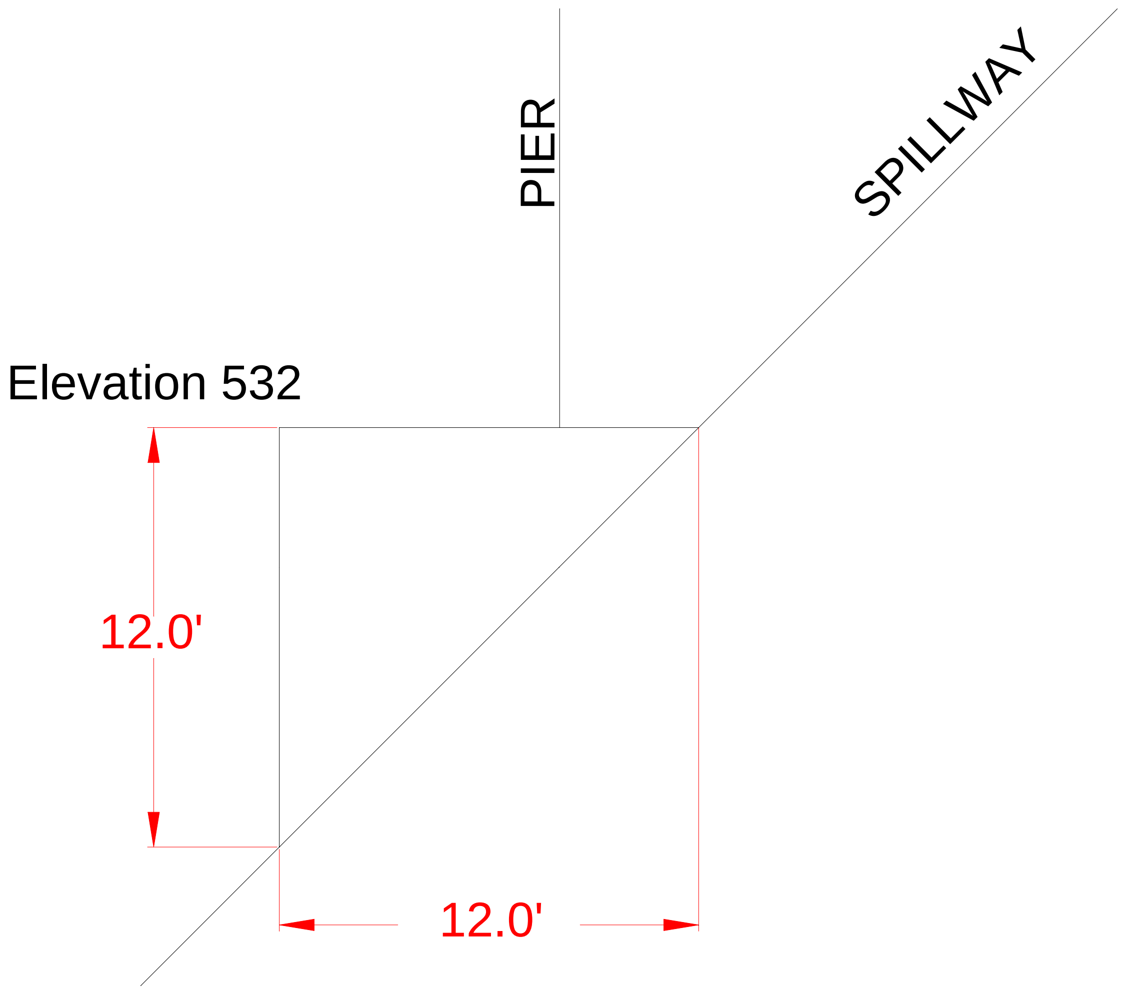


Figure 3. Little Goose Section Model Type II Flow Deflector

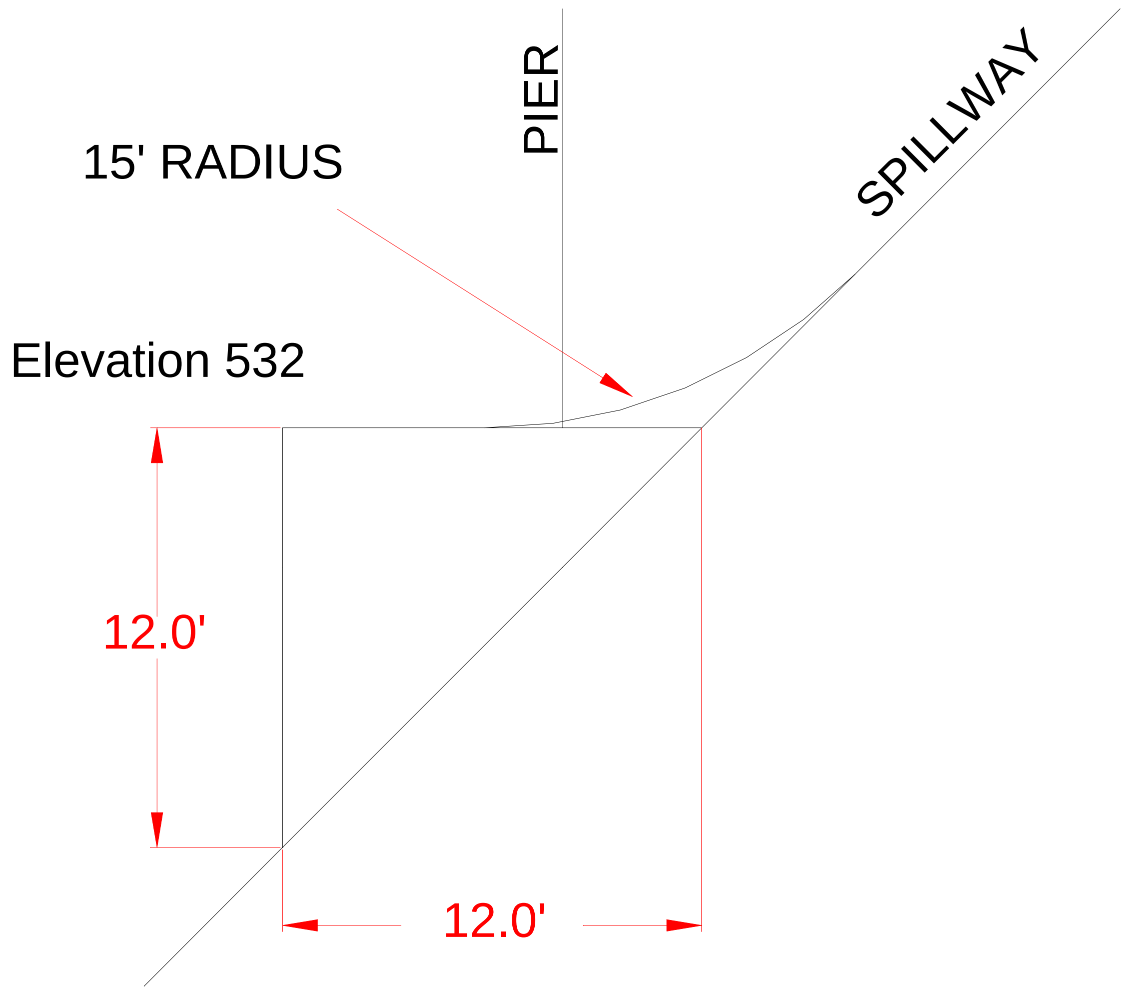


Figure 4. Little Goose Section Model Type IIb Flow Deflector

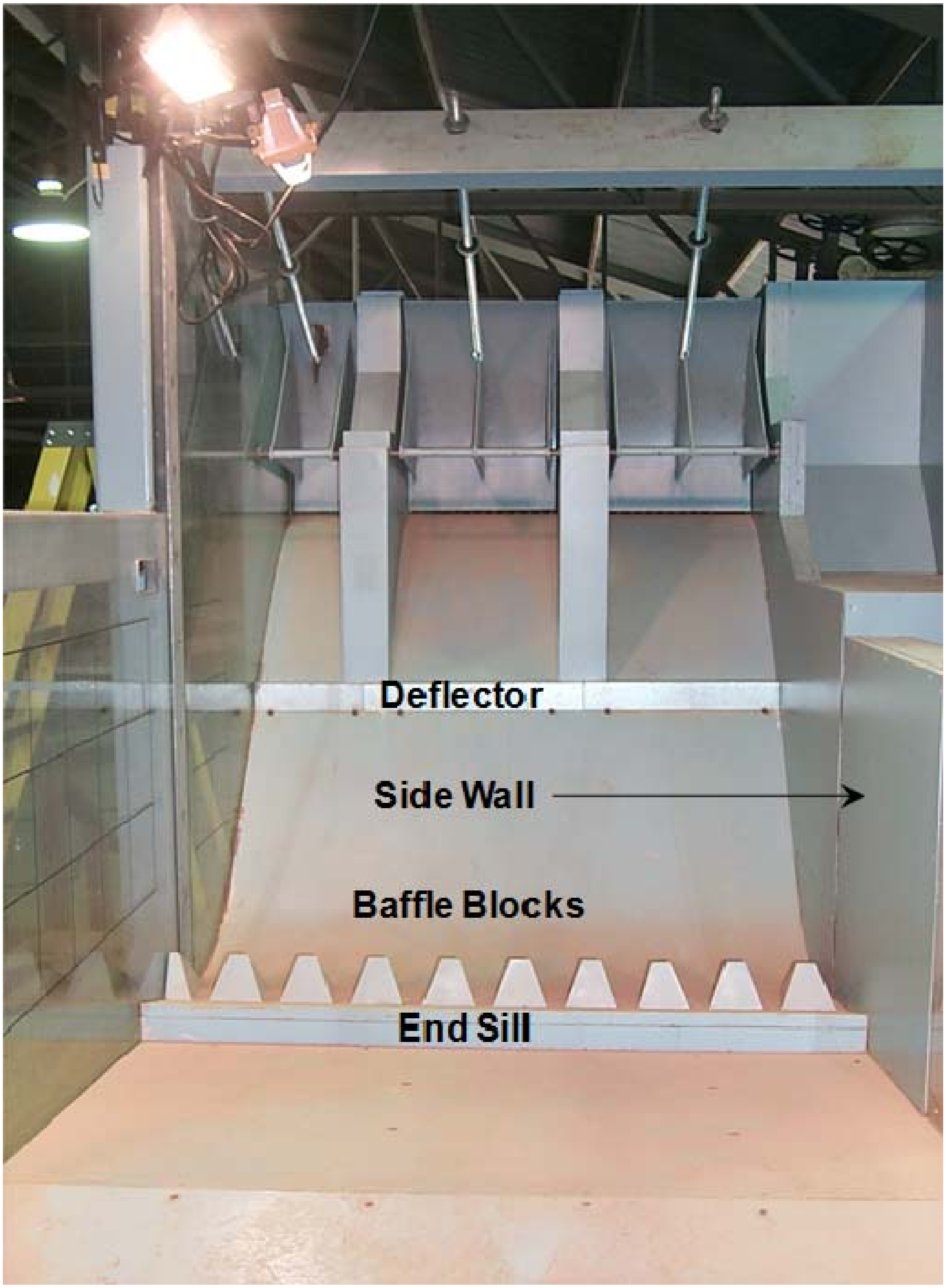


Figure 5. Little Goose Section Model with Type I Deflector

Figure 6. Little Goose Section Model with Type I Deflector, Elevation View

Figure 7. Type I Deflector. Plunging Flow. Gate Opening – 4 ft,
Discharge – 7285.9 kcfs/bay, Pool El – 638, Tailwater El – 532

Figure 8. Type I Deflector. Plunging Flow. Gate Opening – 8 ft,
Discharge – 14976.5 kcfs/bay, Pool El – 638, Tailwater El – 532

Figure 9. Type I Deflector. Undulating Flow. Gate Opening – 2 ft,
Discharge – 4453 kcfs/bay, Pool El – 638, Tailwater El – 540

Figure 10. Type I Deflector. Ramped Surface Jet. Gate Opening – 2 ft,
Discharge – 4452.5 kcfs/bay, Pool El – 638, Tailwater El – 542

Figure 11. Type I Deflector. Surface Jump. Gate Opening – 2 ft,
Discharge – 4452.5 kcfs/bay, Pool El – 638, Tailwater El – 544

Figure 12. Type I Deflector. Submerged Jump. Gate Opening – 2 ft,
Discharge – 4452.5 kcfs/bay, Pool El – 638, Tailwater El – 547

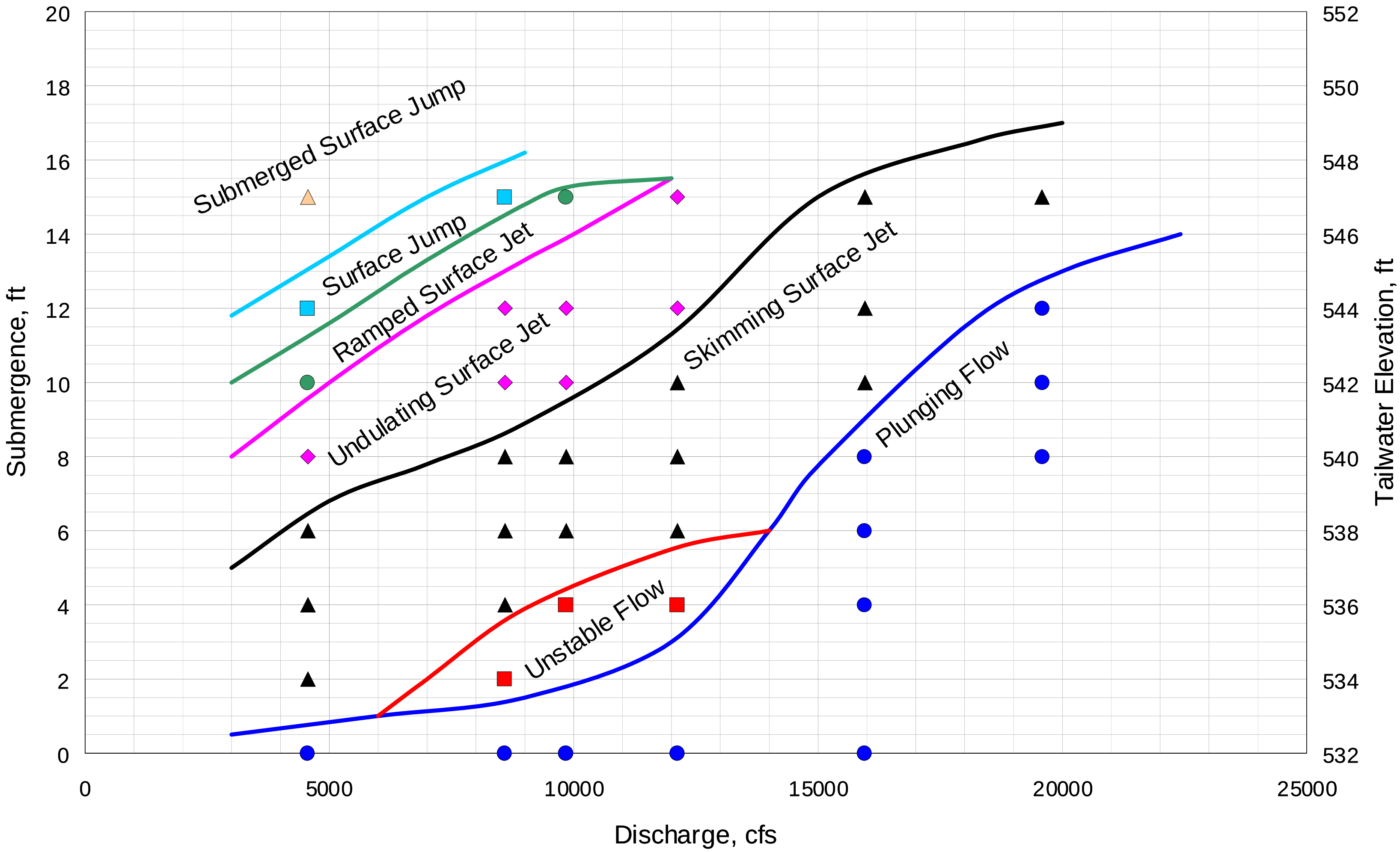


Figure 13. Performance Characteristics of Little Goose Stilling Basin with the Type I Deflector

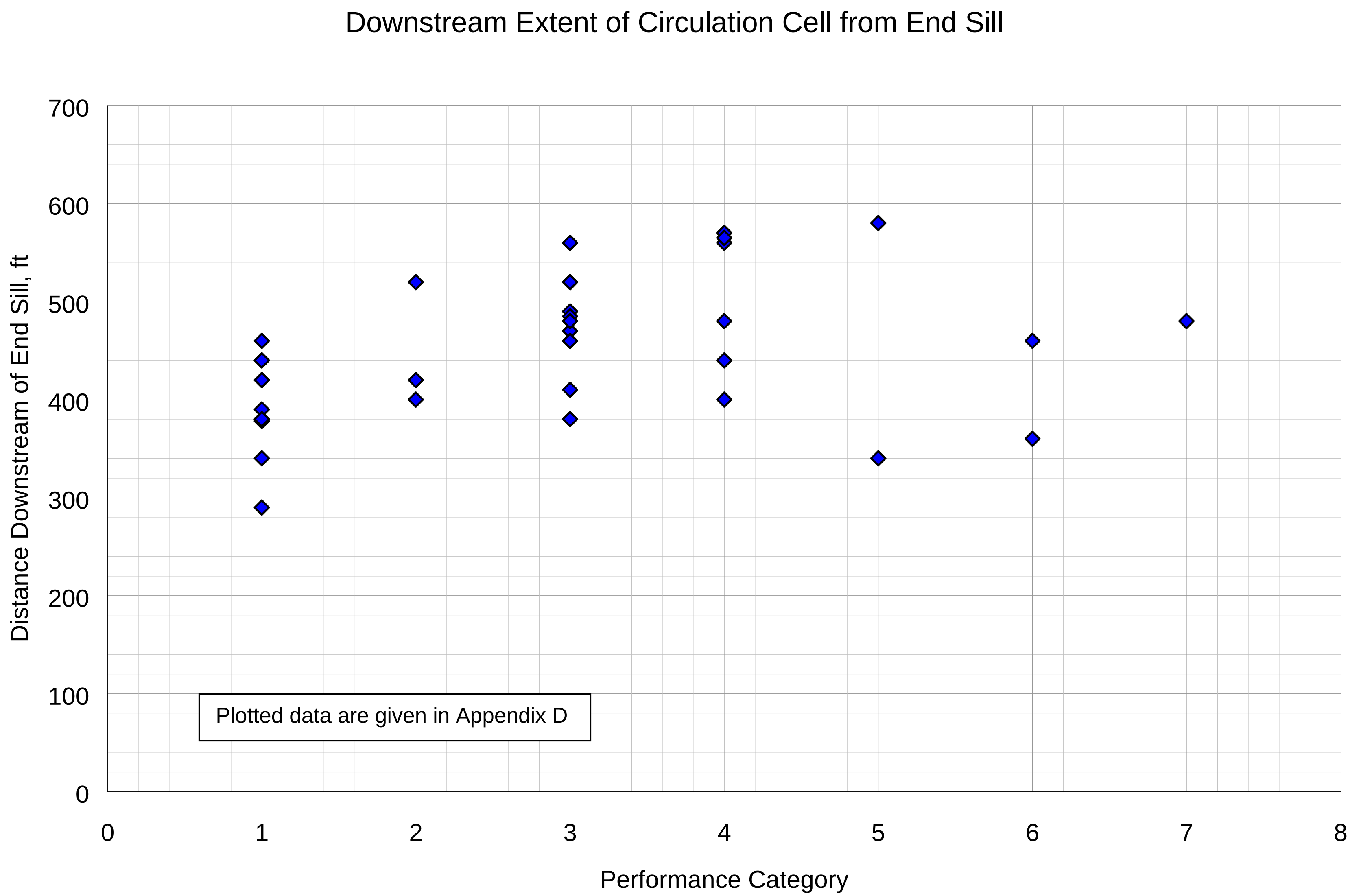


Figure 14a. Downstream Extent of Circulation Cell as a function of performance classification with the Type I Deflector

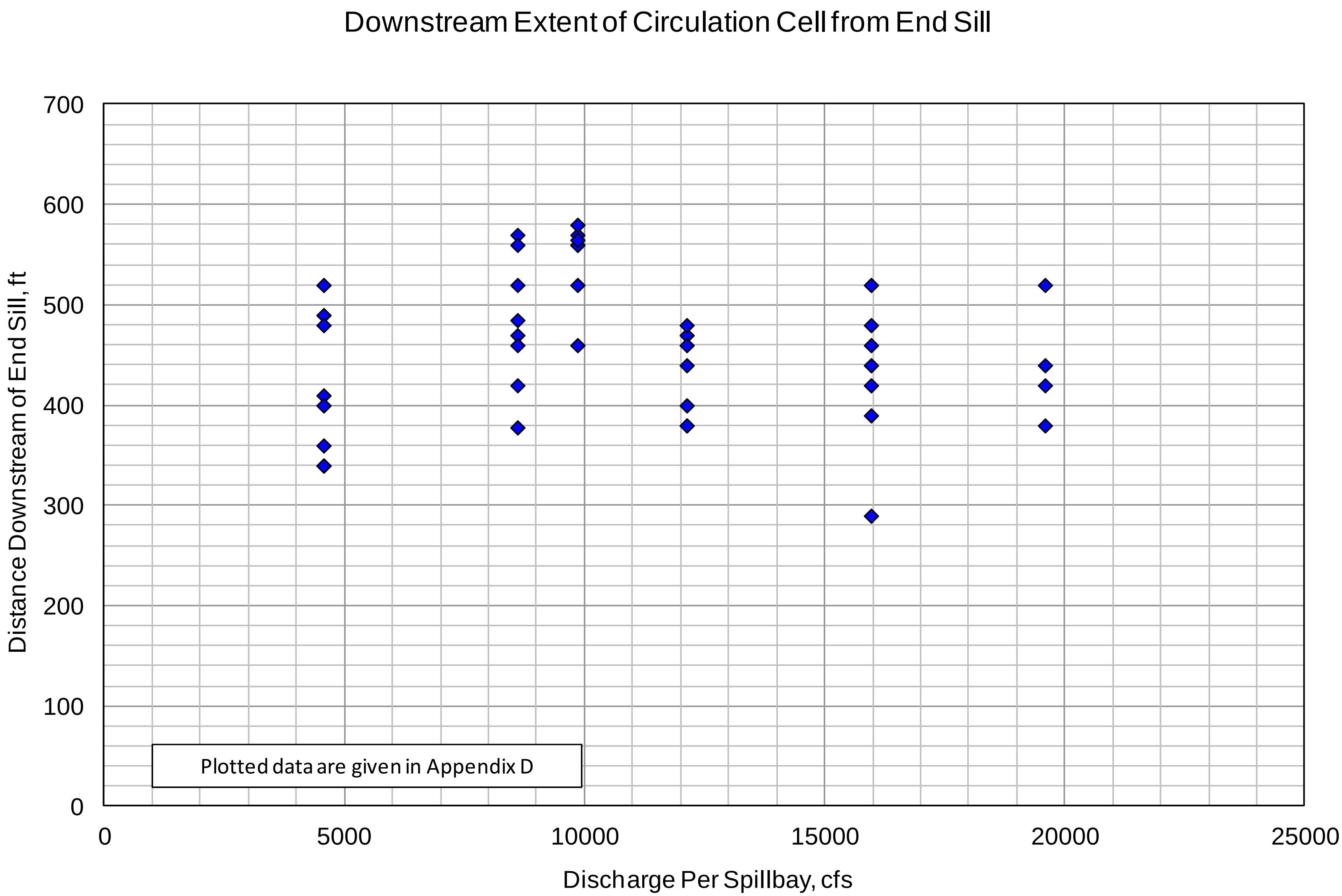


Figure 14b. Downstream Extent of Circulation Cell as a function of discharge per spillbay with the Type I Deflector

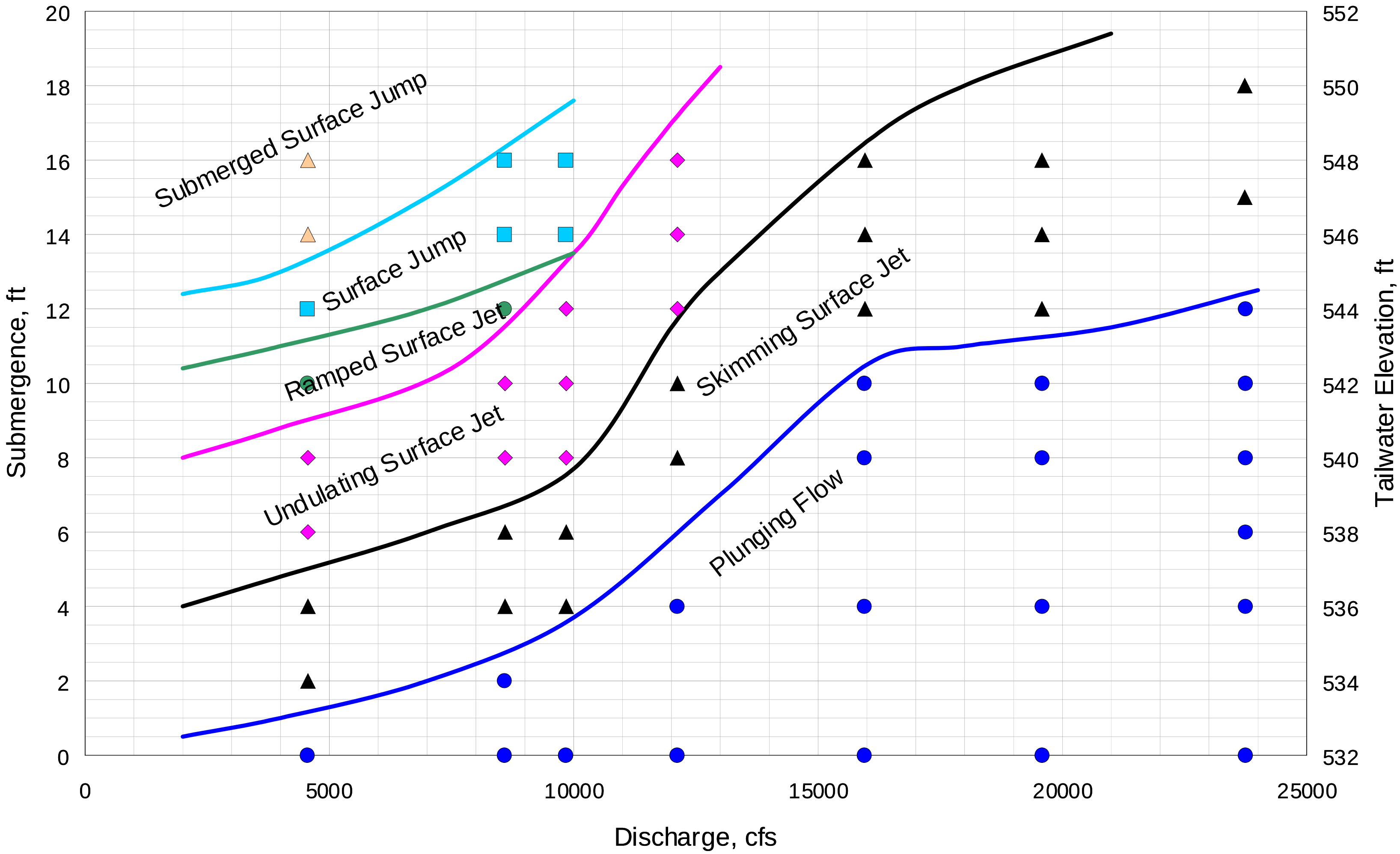


Figure 15. Performance Characteristics of Little Goose Stilling Basin with the Type II Deflector

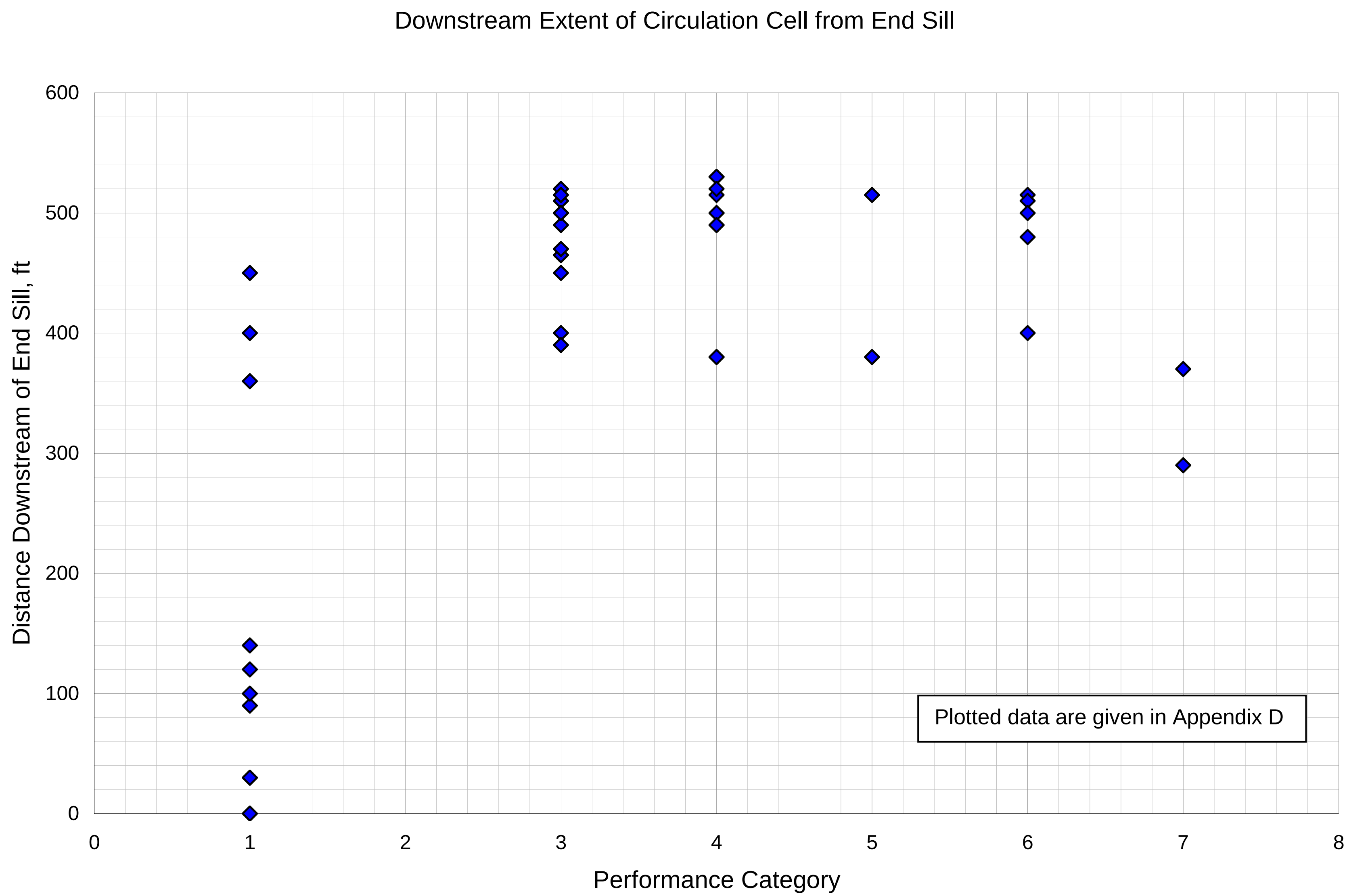


Figure 16a. Downstream Extent of Circulation Cell as a function of performance classification with the Type II Deflector

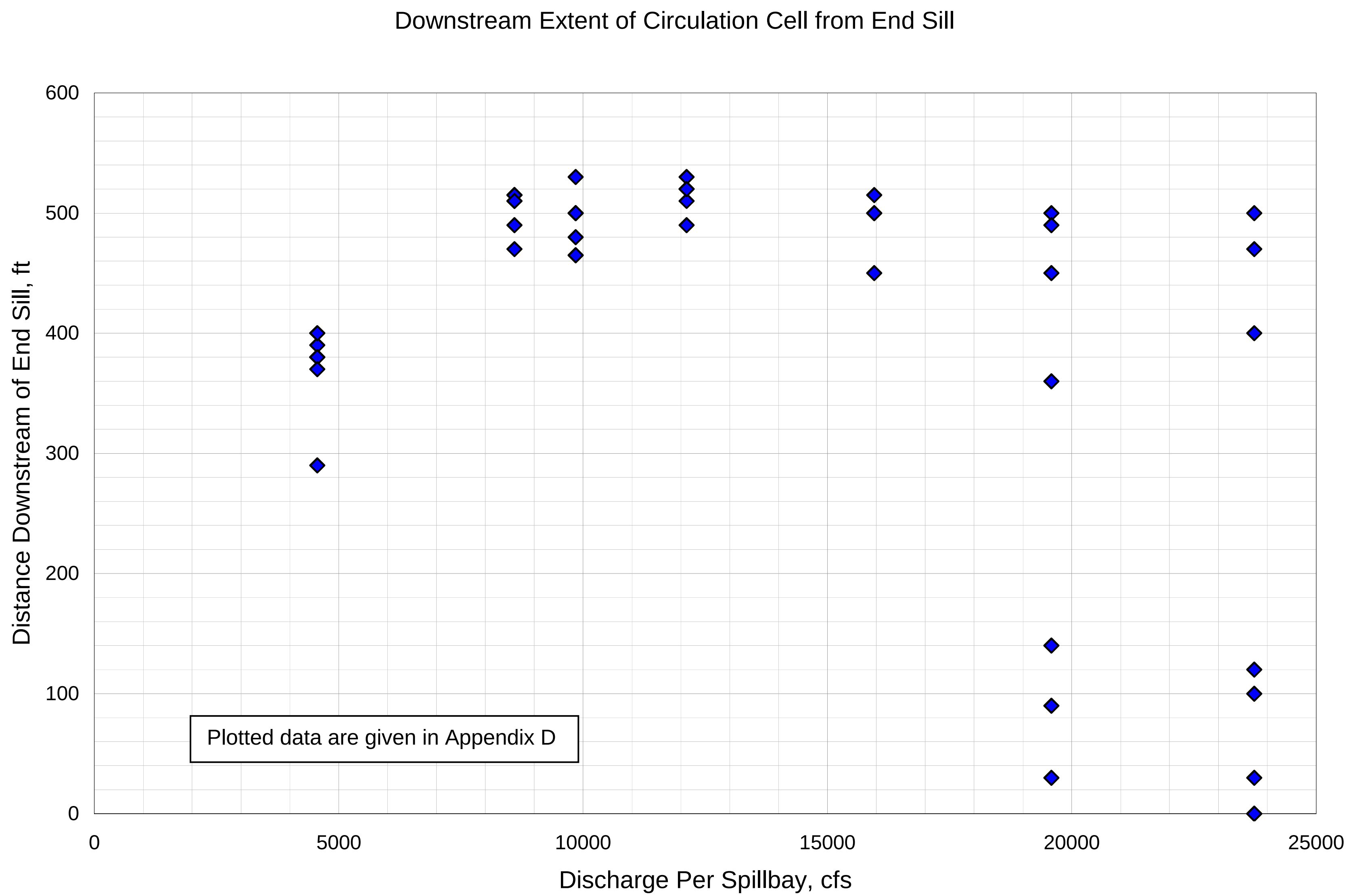


Figure 16b. Downstream Extent of Circulation Cell as a function of discharge per spillbay with the Type II Deflector

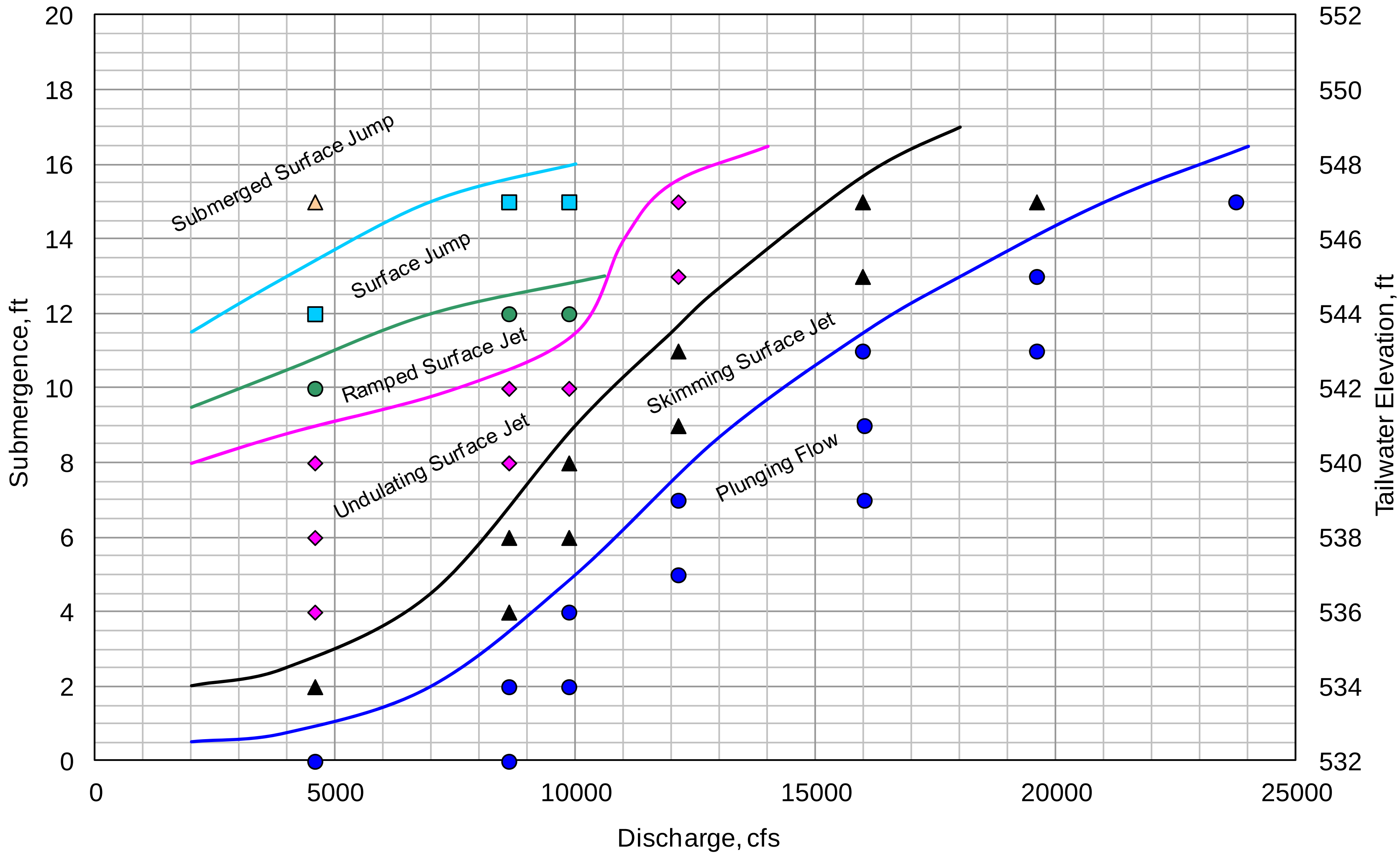


Figure 17. Performance Characteristics of Little Goose Stilling Basin with the Type Ib Deflector

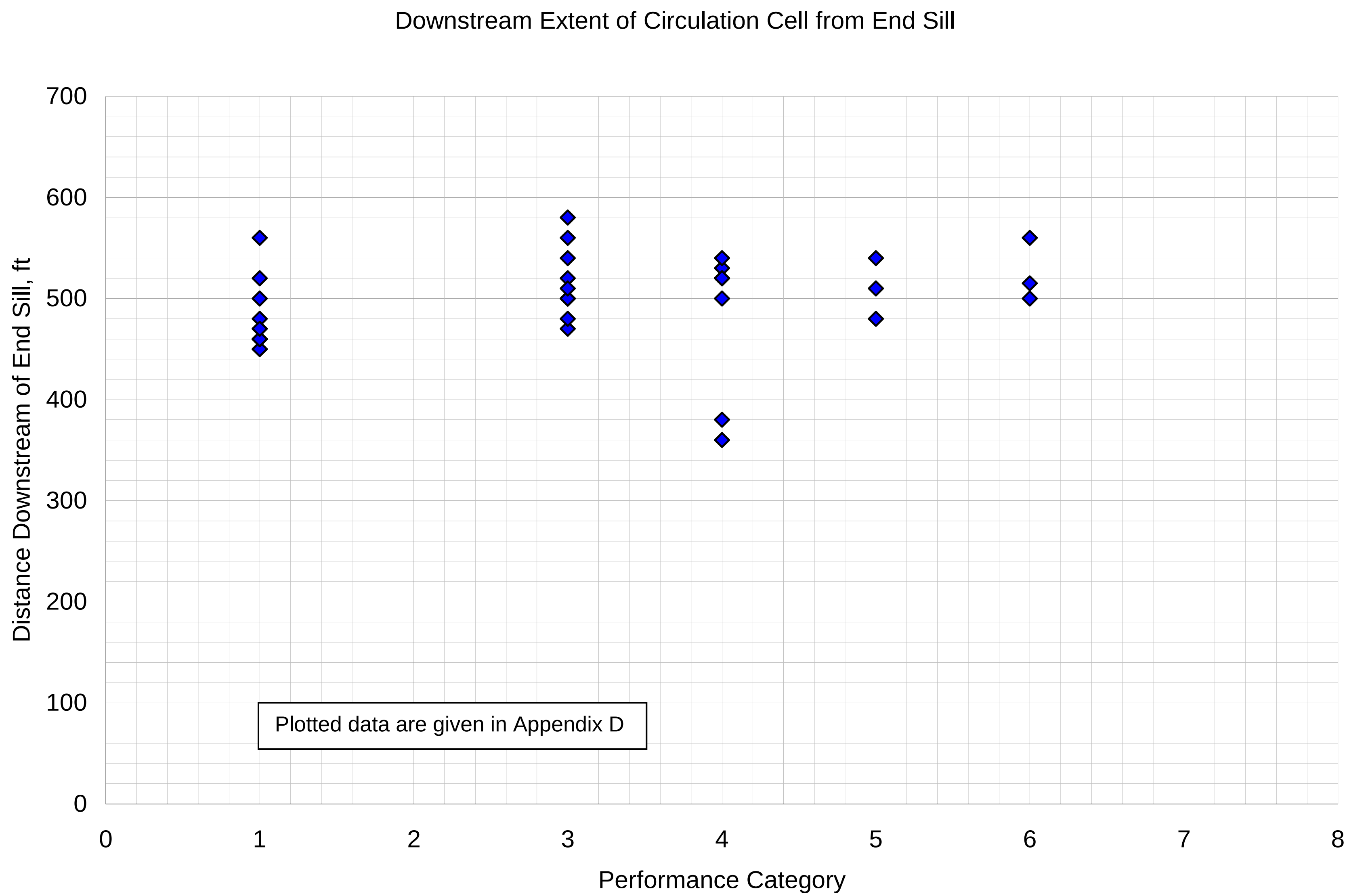


Figure 18a. Downstream Extent of Circulation Cell as a function of performance classification with the Type Ib Deflector

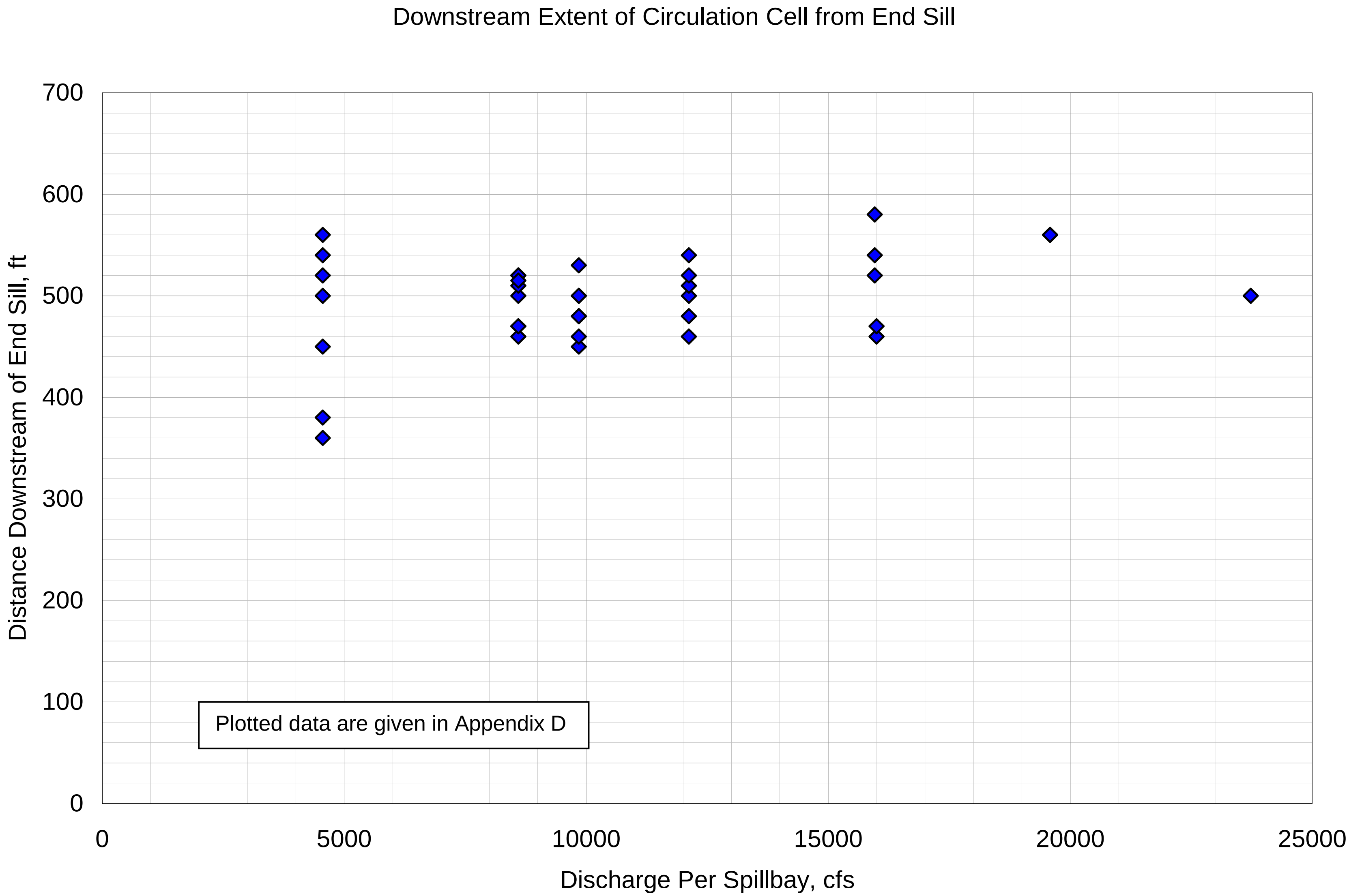


Figure 18b. Downstream Extent of Circulation Cell as a function of discharge per spillbay with the Type Ib Deflector

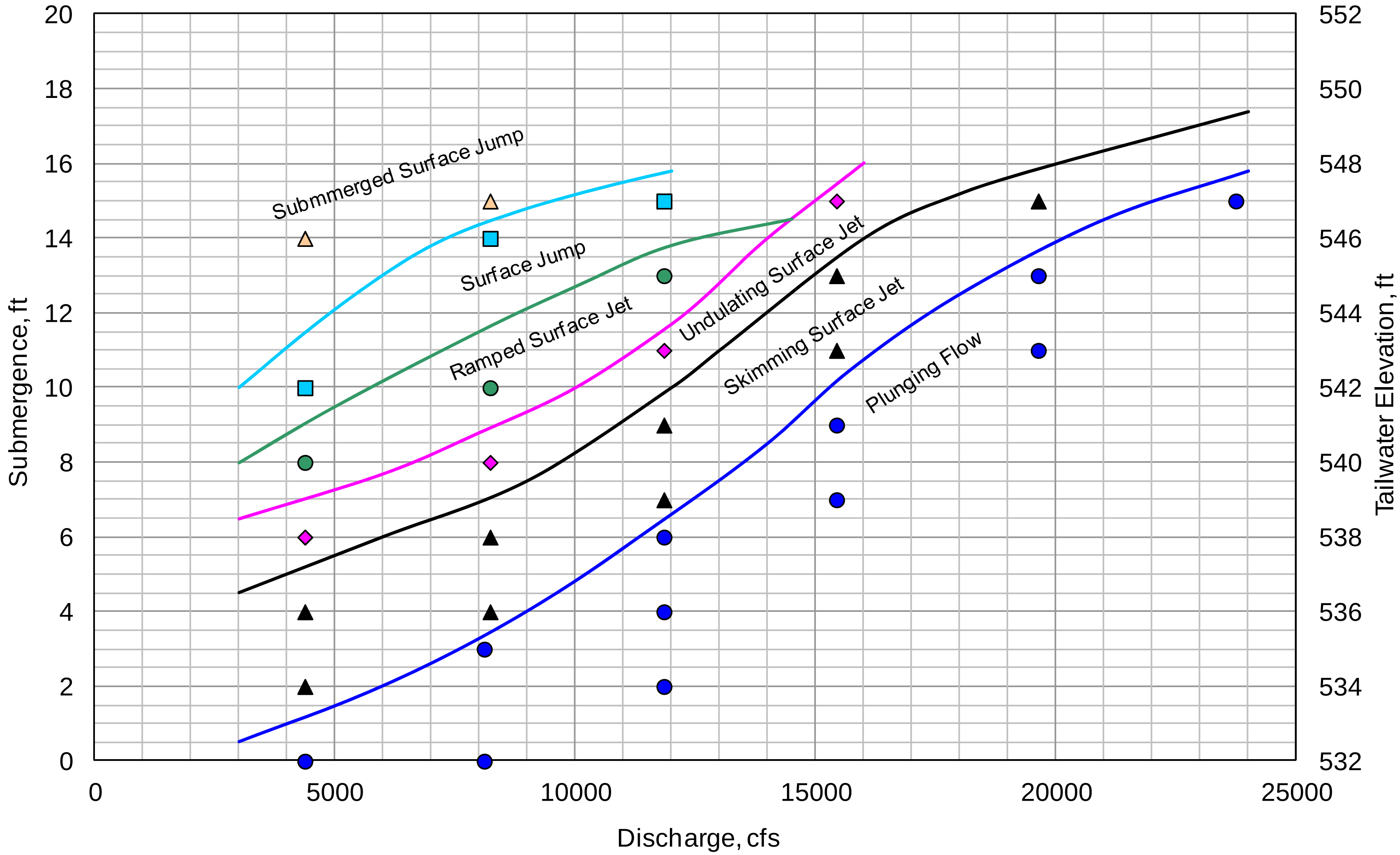


Figure 19. Performance Characteristics of Little Goose Stilling Basin with the Type IIb Deflector

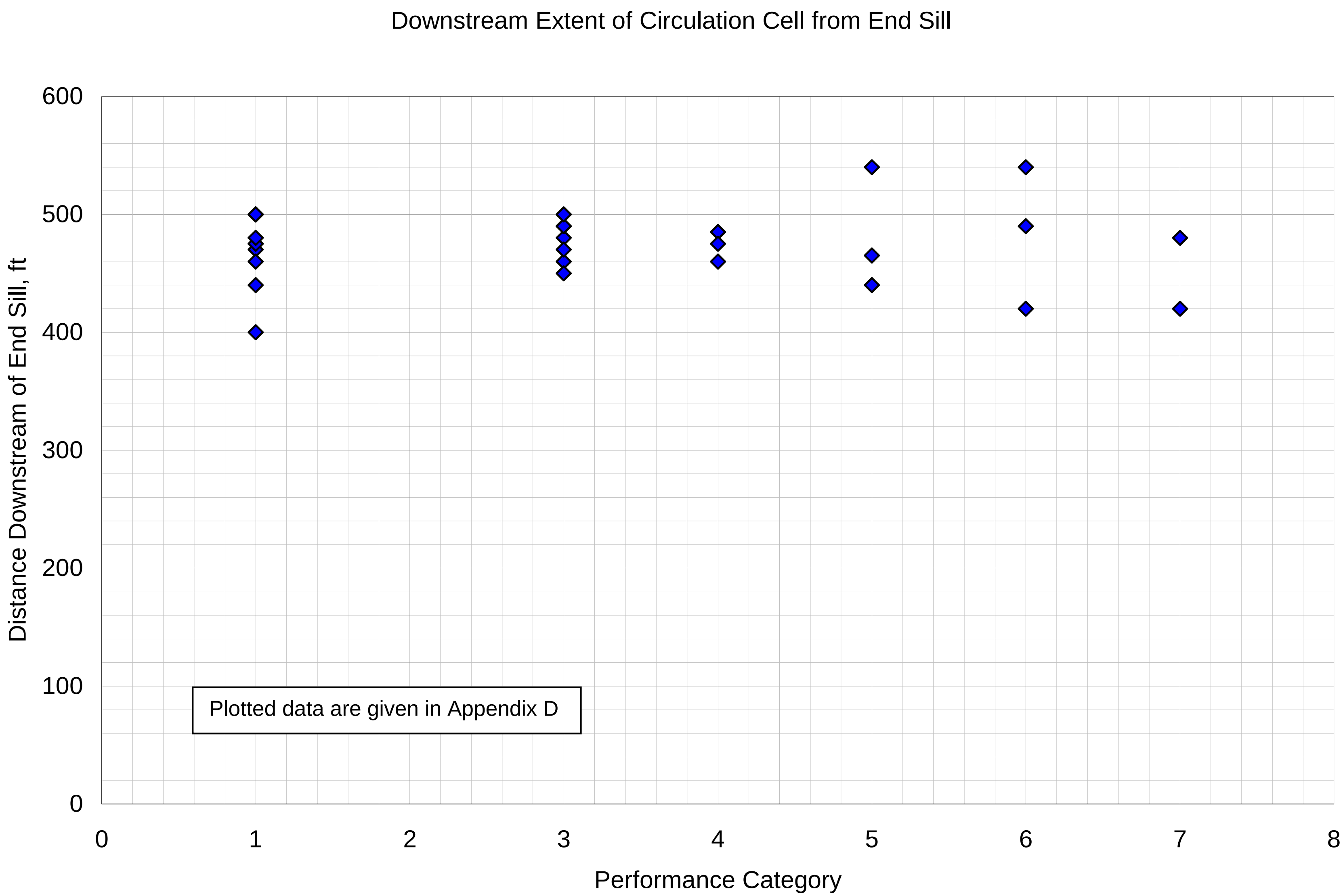


Figure 20a. Downstream Extent of Circulation Cell as a function of performance classification with the Type IIb Deflector

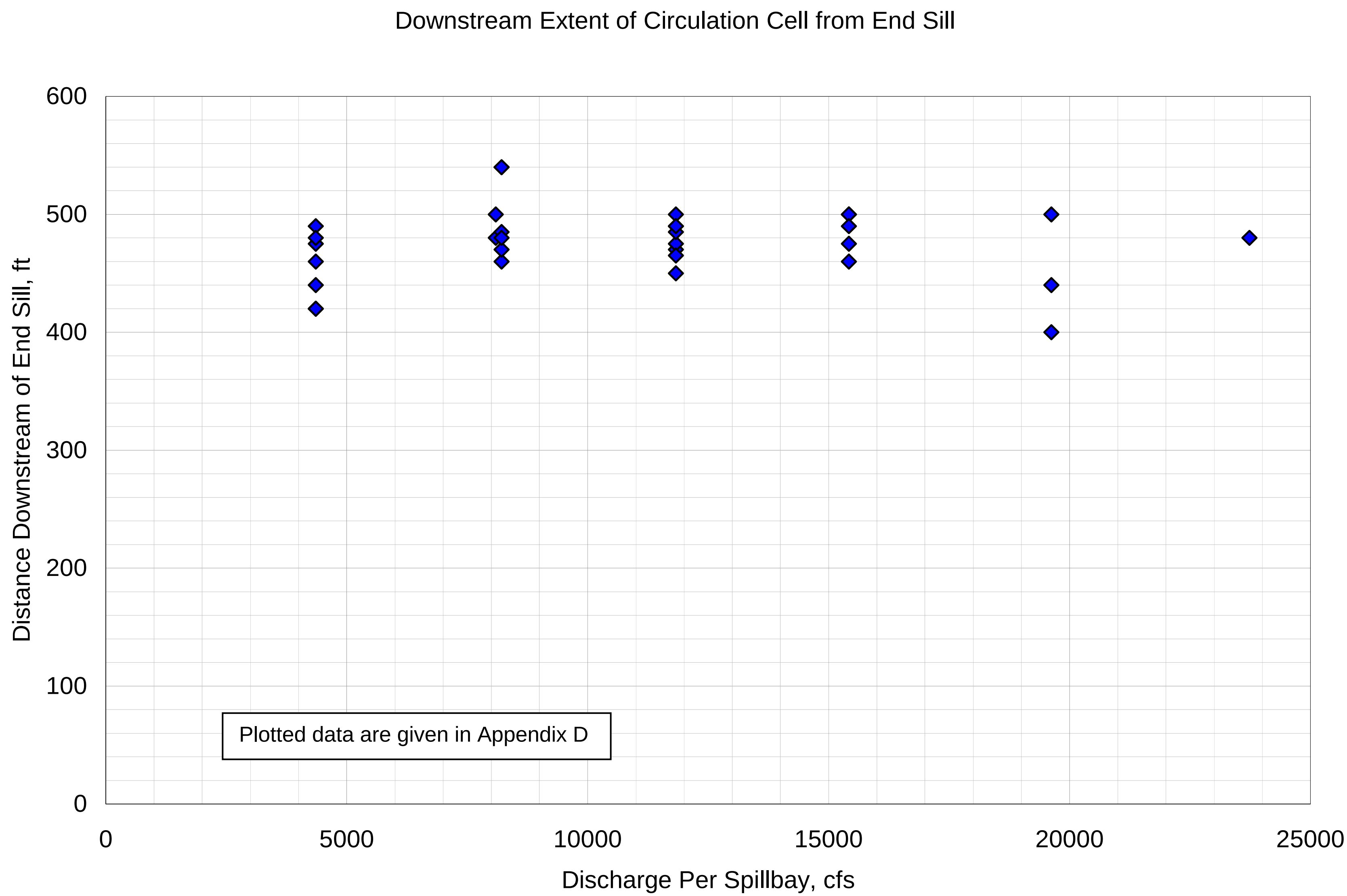


Figure 20b. Downstream Extent of Circulation Cell as a function of discharge per spillbay with the Type IIb Deflector

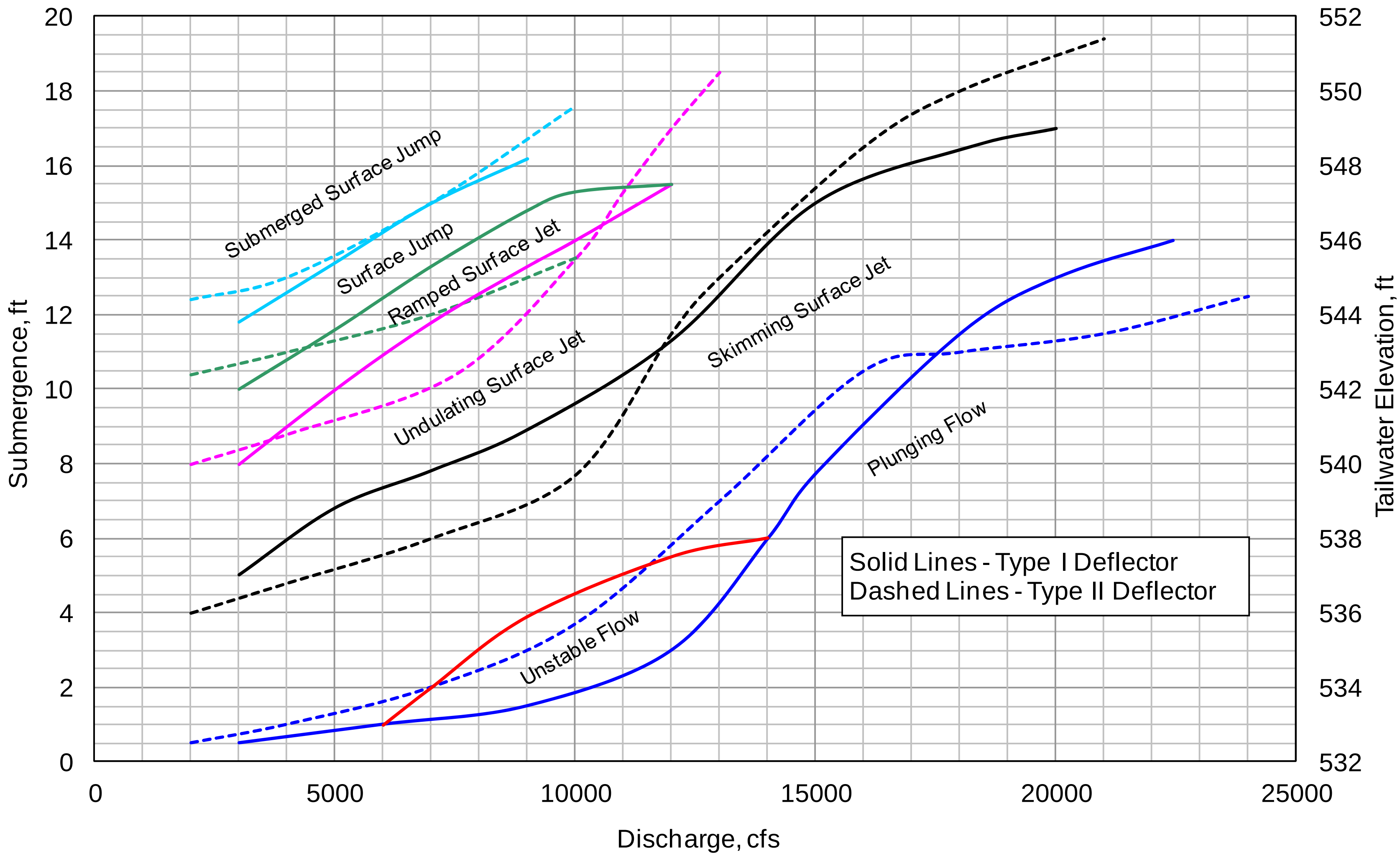


Figure 21. Comparison of the Performance Characteristics of Type I and Type II Deflectors

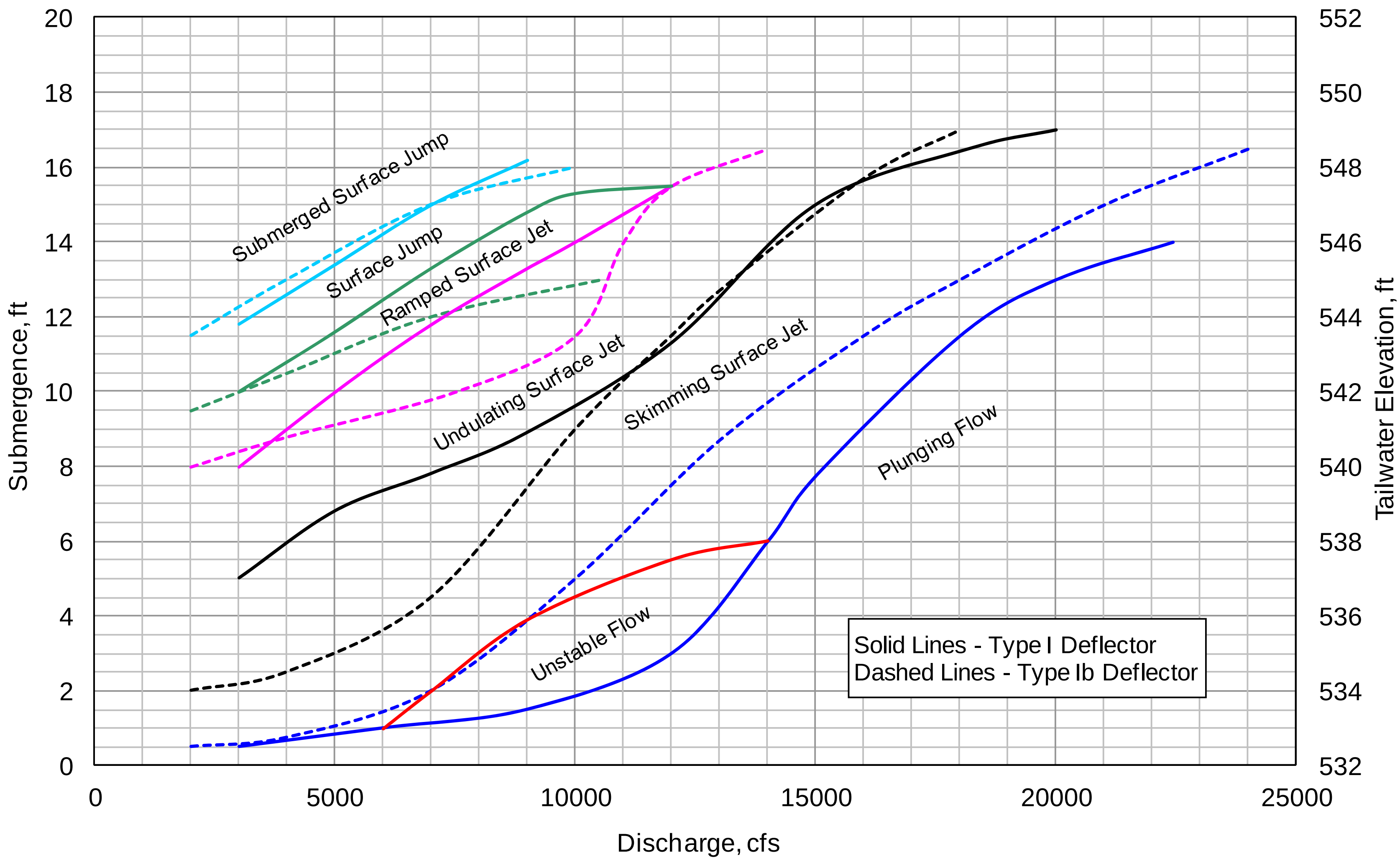


Figure 22. Comparison of the Performance Characteristics of Type I and Type Ib Deflectors

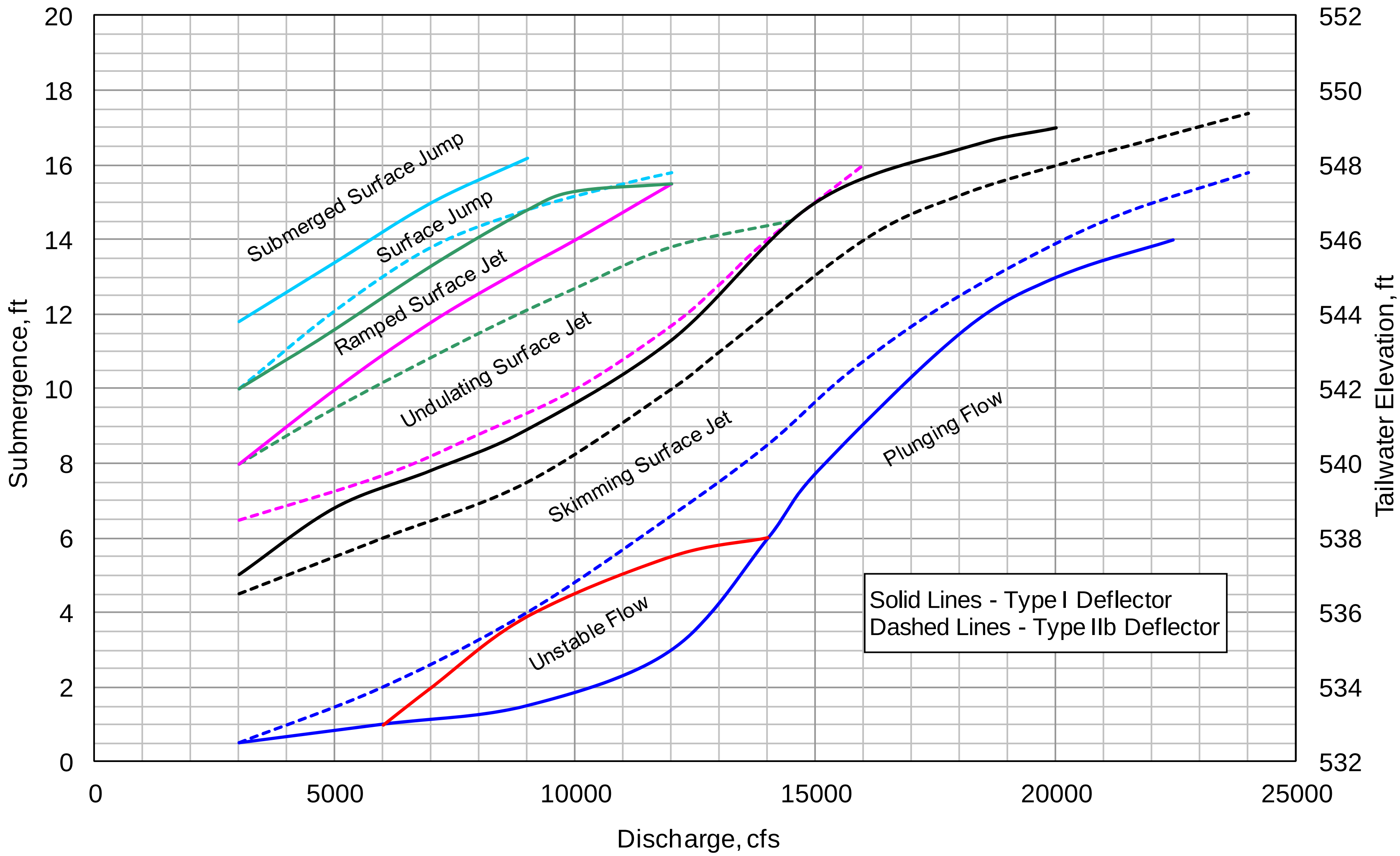


Figure 23. Comparison of the Performance Characteristics of Type I and Type IIb Deflectors

Appendix A. Scope of Work

A. Objective I. Define Operational Characteristics of Deflector and Stilling Basin. The hydraulic conditions in the Little Goose stilling basin and tailrace will be investigated to define the performance characteristics of the existing deflector design and stilling basin design, alternative deflector designs, and additional endbay deflectors.

a. WES will define the performance of the existing deflector[1] design with a set of experiments over a wide range of discharge and tailwater elevations.

Configuration. Existing deflector at el 532.0 on all bays, including the endbay. A dividing wall will be installed in line with the stilling basin wall for a significant distance down through the tailrace to create a more 2-dimensional model.

Experimental Operations. A uniform spill distribution will be set across all bays. The experimental discharges and tailwater range are shown in Table 1. For these experiments, the pool will be held at el 638.0. For each discharge, tailwater will be varied over a range of elevations in order to define the different zones of hydraulic characteristics. In general, this will require setting 10 tailwater el's for each discharge.

Table 1. Discharge and tailwater range for Objective A.a tasks

Approx Discharge, kcfs/bay	River Discharge without Powerhouse*, kcfs	River Discharge* with Max Powerhouse, kcfs	Minimum tailwater	Maximum Tailwater
2.5	15	135	532	547
5	30	150	532	547
7.5	45	165	532	547
10	60	180	532	547
12.5	75	195	532	547
15	90	210	532	547
17.5	105	225	532	547
20	120	240	532	547
*Assumes uniform distribution of discharge across 6 gates and maximum powerhouse discharge of 120 kcfs				

WES will classify, digitally photograph, and record the flow conditions on video tape. A digital photo album will be prepared and posted to the modeling web page. Performance curves will be developed. The vertical extent of the surface jet will be measured for comparison with later testing with lateral entrainment flows. The downstream extent of the vertical circulation cell will be measured with injected dye. For those conditions with the largest circulation cell, i.e., surface jet flow, velocity profiles will be measured at the endsill and at two

1 Deflectors will be held in place by magnets to allow quick replacement.

locations in the tailrace. The experimental results will be summarized in a memorandum.

b. WES will define the performance of alternative deflector designs with a set of experiments over a wide range of discharge and tailwater elevations.

<u>Configuration.</u> Deflectors of 10- and 12-ft length with transition radius and pier extensions, if needed on all bays, including the endbay. A dividing wall will be installed in line with the stilling basin wall for a significant distance down through the tailrace to create a more 2-dimensional model.

<u>Experimental Operations.</u> A uniform spill distribution will be set across all bays. Discharges and tailwater elevations will range through those given in Table 2. This will require setting 8 tailwater el's for each discharge up to 20 kcfs per spillbay. Thereafter, performance for 3 tailwater elevations will be investigated.

Table 2. Discharge and tailwater range for Objective A.b tasks

Approx Discharge, kcfs/bay	River Discharge without Powerhouse*, kcfs	River Discharge* with Max Powerhouse, kcfs	Minimum tailwater	Maximum Tailwater
2.5	15	135	532	547
5	30	150	532	547
7.5	45	165	532	547
10	60	180	532	547
15	90	210	532	547
20	120	240	532	547
40	240	360	?	?
75	450	570	?	?
100	600	720	?	?

*Assumes uniform distribution of discharge across 6 gates and maximum powerhouse discharge of 120 kcfs

WES will classify, digitally photograph, and record the flow conditions on video tape. A digital photo album will be prepared and posted to the modeling web page. Performance curves will be developed. The vertical extent of the surface jet will be measured for comparison with later testing with lateral entrainment flows. The downstream extent of the vertical circulation cell will be measured with injected dye. For those conditions with the largest circulation cell, i.e., surface jet flow, velocity profiles will be measured at the endsill and at two locations in the tailrace. The experimental results and analysis will summarized in a short memorandum

c. WES and District personnel will jointly design the outside-bay deflectors based on the performance curves observed during previous experiments.
WES will install and experimentally evaluate the new deflector in the outside bay. For comparison to later experiments with a dividing wall between stilling basin and powerhouse, debris transport will be investigated.

Configuration. New deflector on Bay 1 (end bay) and existing deflectors on remaining bays. Flow field will include region downstream of non-overflow section between spillway and lock, i.e, no dividing wall extended downstream of south stillbasin sidewall. Lateral inflow through flume wall to simulate hydropower releases. Debris will be introduced to the tailrace that simulates 1-ft-diameter and smaller cobbles.

Experimental Operations. A uniform spill distribution will be set across all bays. Discharges and tailwater elevations will range through those given in Table 3. This will require setting 8 tailwater el's for each discharge up to 20 kcfs per spillbay. Three lateral discharges will be introduced through the flume wall: 0, 10 kcfs, and 20 kcfs.

Table 3. Discharge and tailwater range for Objective A.c tasks

Approx Discharge, kcfs/bay	River Discharge without Powerhouse*, kcfs	River Discharge* with Max Powerhouse, kcfs	Minimum tailwater	Maximum Tailwater
2.5	20	140	532	547
5	40	160	532	547
7.5	60	180	532	547
10	80	200	532	547
15	120	240	532	547
20	160	280	532	547

*Assumes uniform distribution of discharge across 8 gates and maximum powerhouse discharge of 120 kcfs

WES will verify the classification of flow conditions. Each flow condition will be digitally photographed and recorded on video tape. The interaction of the flow from Bay 1 and the other bays will be investigated by placing directional yarn on a grid in the stilling basin and tailrace and mapping the direction of stilling basin floor velocities. The vertical extent of the surface jet will be measured for comparison with earlier measurements. The horizontal circulation cell in the tailrace will be defined by size and strength (velocity profiles at 2 locations in tailrace). The experimental results and analysis will summarized in a short memorandum.

The downstream extent of the vertical circulation cell will be measured with injected dye. For those conditions with the largest circulation cell, i.e., surface jet flow, velocity profiles will be measured at the endsill and at two locations in the tailrace.

WES will identify the minimum spillway flow and tailwater elevation associated with debris movement from downstream, over the end sill, and into the stilling basin. WES will map where material originates and where it is deposited. Debris transport will be compared to the post-wall characteristics. These experiments will be summarized in a short memorandum.

B. Objective II. Define the performance characteristics of several alternatives. The hydraulic performance of several additional alternatives will also be evaluated, including a divider wall between the powerhouse and spillway to limit powerhouse entrainment and modifications to the stilling basin and tailrace (yet to be defined).

a. WES will design a divider wall to separate the powerhouse discharge and the spillway discharge. For these experiments, a lateral flow to simulate powerhouse releases, will be introduced through the side of the flume wall.

Configuration. New deflector on Bay 1 (end bay) and existing deflectors on remaining bays. Flow field will include region downstream of non-overflow section between spillway and lock but with a variable-length dividing wall extended downstream of south stillbasin sidewall.

Experimental Operations. A uniform spill distribution will be set across all bays. Five discharges and 3 tailwater elevations will be investigated (Table 4). Three lateral discharges will be introduced through the flume wall: 0, 10 kcfs, and 20 kcfs.

Table 4. Discharge and tailwater range for Objective B.a tasks

Approx Discharge, kcfs/bay	River Discharge without Powerhouse*, kcfs	River Discharge* with Max Powerhouse, kcfs	Minimum tailwater	Maximum Tailwater
7.5	45	165	TBD	TBD
5	30	150	TBD	TBD
10	60	180	TBD	TBD
15	90	210	TBD	TBD
25	150	270	TBD	TBD

*Assumes uniform distribution of discharge across 6 gates and maximum powerhouse discharge of 120 kcfs

WES will conduct preliminary experiments with several wall lengths to determine the minimum length required to eliminate lateral entrainment by the surface jet. Once designed, the wall will be installed in the model.

WES will verify the classification of flow conditions. Each flow condition will be digitally photographed and recorded on video tape. The interaction of the flow from Bay 1 and the other bays will be investigated by placing directional yarn on a grid in the stilling basin and tailrace and mapping the direction of stilling basin floor velocities. The vertical extent of the surface jet will be measured for comparison with earlier measurements. The downstream extent of the vertical circulation cell will be measured with injected dye. For those conditions with the largest circulation cell, i.e., surface jet flow, velocity profiles will be measured at the endsill and at two locations in the tailrace. The experimental results and analysis will summarized in a short memorandum.

b. WES will investigate other alternatives that will be developed later in the study.

Configuration. To be determined.

Experimental Operations. To be determined.

C. Objective III. Substantial debris movement has already occurred in the Little Goose tailrace. Based on hydrographic surveys and previous studies (USACE 1984), the immediate area downstream of the still basin has been eroded and the material forms a tongue-like shape down the tailrace. The bathymetry of the section model is fixed and represents an "averaged" shape. The potential for debris transport from the tailrace into the stilling basin will be investigated.

Configuration. New deflector on Bay 1 (end bay) and existing deflectors on remaining bays. Flow field will include region downstream of non-overflow section between spillway and lock but with a dividing wall extended downstream of the south stilling basin sidewall.

Experimental Operations. Based on previous measurements of tailrace velocity, the flow condtions that offer the greatest potential to transport material from the tailrace into the roller bucket stilling basin will be investigated. A uniform spill distribution will be set across all bays. Eight discharges and 3 tailwater elevations will be investigated (Table 5).

Table 5. Discharge and tailwater range for Objective C

Approx Discharge, kcfs/bay	River Discharge without Powerhouse*, kcfs	River Discharge* with Max Powerhouse, kcfs	Minimum tailwater	Maximum Tailwater
2.0	16	136	TBD	TBD
4.0	32	152	TBD	TBD
6.0	48	168	TBD	TBD
10.0	80	200	TBD	TBD
15.0	120	240	TBD	TBD
25.0	200	320	TBD	TBD
50.0	400	520	TBD	TBD
100.0	800	920	TBD	TBD

*Assumes uniform distribution of discharge across 8 gates and maximum powerhouse discharge of 120 kcfs

WES will validate the previous measurements and performance and introduce debris into the tailrace that simulates the movement of 1-ft-diameter and smaller cobbles. Velocities at the channel bottom will be measured at the stilling basin end sill and at 100 ft downstream of the end sill, if not previously acquired.

WES will verify the minimum spillway flow and tailwater elevation associated with debris movement from downstream, over the end sill, and into the stilling basin. WES will map where material originates and where it is deposited.

Each test condition will be digitally photographed and recorded on video. Debris transport will be compared to the pre-wall characteristics. These experiments will be summarized in a short memorandum.

D. Objective IV. In past studies, cavitation pressures were of concern for the vertical face of the deflector and on the side of pier extensions. The model has the flexibility to add pressure taps on a final design deflector and pier extensions. If these average pressures show potential for negative pressure spikes, a high-frequency pressure transducer will be installed and the pressure fluctuations on the deflector face will be measured to determine the cavitation potential. The detail plan of study to accomplish this task will be developed based on results from previous tasks.

Configuration. New deflector on Bay 1 (end bay) and existing deflectors on remaining bays. Three piezometers will be installed on the vertical face of the deflector and two piezometers will be installed on the sidewall of the pier extensions (if they are included in the design). Flow field will include region downstream of non-overflow section between spillway and lock but with a dividing wall extended downstream of the south stilling basin sidewall.

Experimental Operations. A uniform spill distribution will be set across all bays. Three discharges and 3 tailwater elevations will be investigated.

WES will measure the average pressure at each piezometer and estimate the potential for cavitation pressures occurring because of pressure flucuations. If potential exists, WES will recommend and provide a scope of work to determine the magnitude of pressure flucuations.

E. Objective V. A technical report will be developed that consolidates the previous memoranda and includes overall conclusions and recommendations.

Appendix B. Description of Stilling Basin Flow Categories

a. Plunging flow (Figure B1) includes *aerated plunging flow*, which occurred when the underside of the surface jet was vented at the downstream end of the deflector; *unstable aerated plunging flow,* which occurred when the underside venting of the surface was inconsistent; and *non-aerated plunging flow,* which occurred when the underside aeration ceased, but there was sufficient momentum to still cause a plunging flow off of the deflector.

b. *Unstable or surging flow* occurred with the flow alternately attempting to ride the surface of the tailwater, but then plunging to the stilling basin floor with tailwater surging over the plunging flow (Figure B2).

c. *Skimming flow or surface jet* (Figure B3) occurred when the spillway jet remained along the surface of the tailwater with a relatively flat water surface with no plunging action and little downwelling.

d. *Undulating flow or an undulating surface jet* (Figure B4) occurred when the spillway jet coming off of the deflector would ride over the downstream water surface forming an undulating surface with standing waves.

e. *Ramped surface jet* (a refinement of previous classifications) occurred when the spillway jet coming off of the deflector would “ramp up” steeply on the downstream water surface forming an undulating surface with significant downwelling at the standing waves (Figure B5).

f. *Surface jump* (Figure B6) occurred when a hydraulic roller formed at the deflector, resulting in a hydraulic jump that was elevated off the stilling basin floor. This includes an *unstable surface jump*, which occurs when the sloping upstream face of the surface jet attempts to break over into a "surface jump," but retreats and starts again.

g. *Submerged surface jump* (Figure B7) occurred when, with higher tailwater, the surface jump was inundated on the deflector, resulting in a submerged hydraulic jump that was elevated off the stilling basin floor.

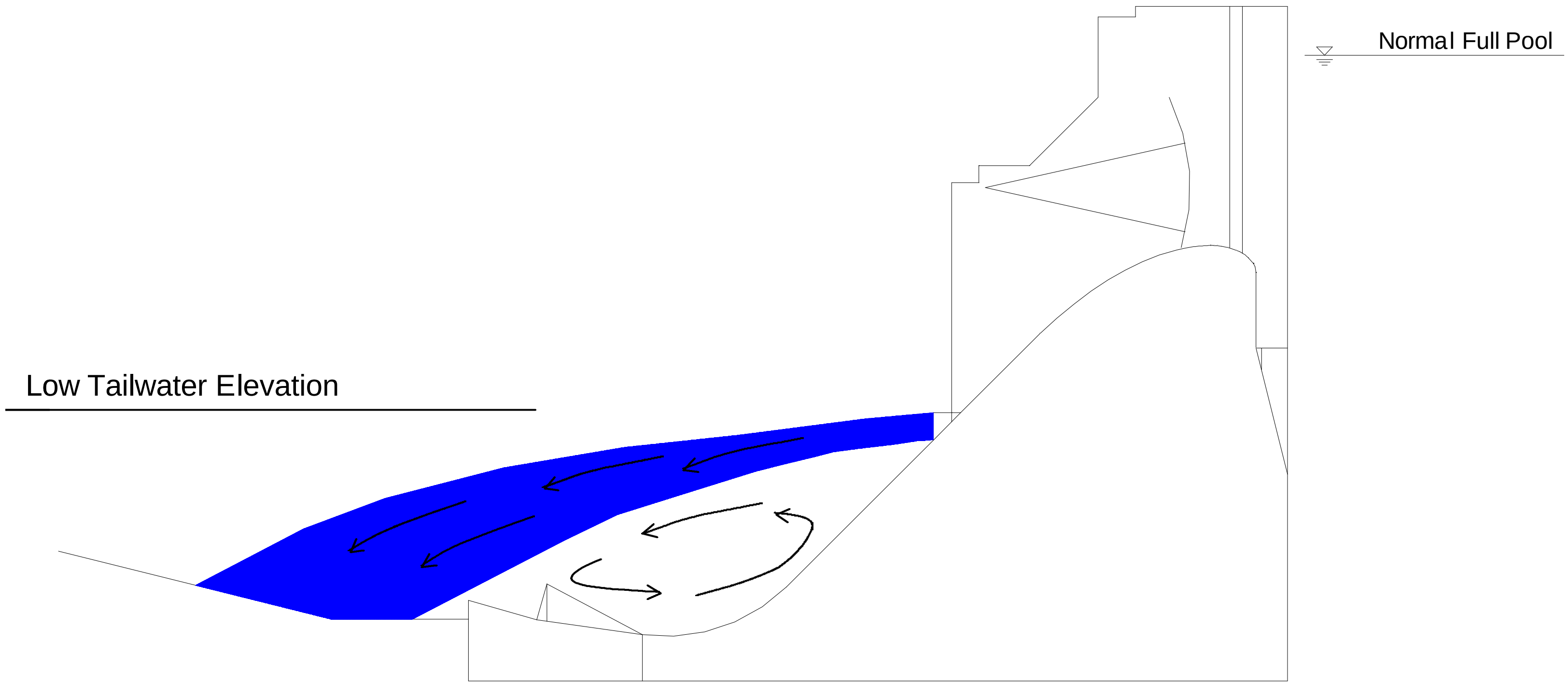


Figure B1. Plunging Flow

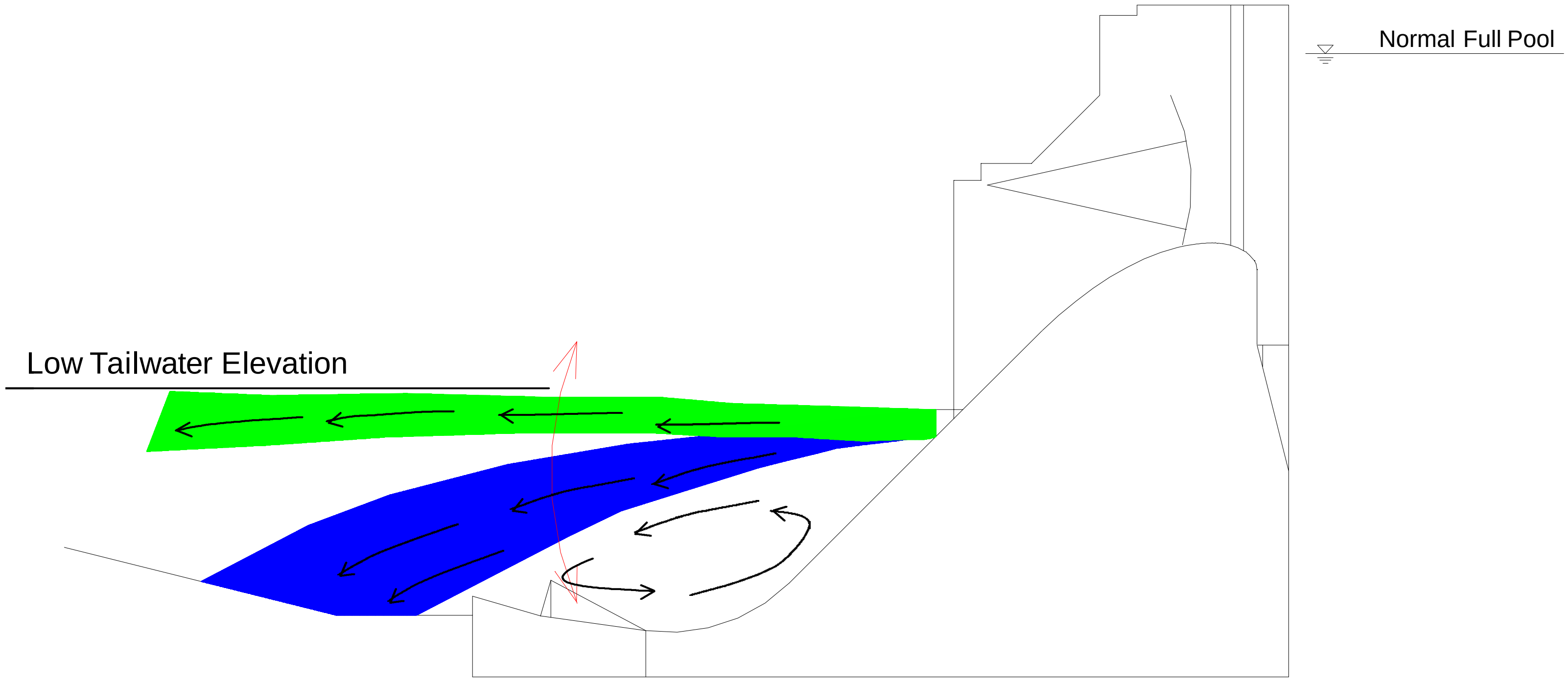


Figure B2. Unstable Flow

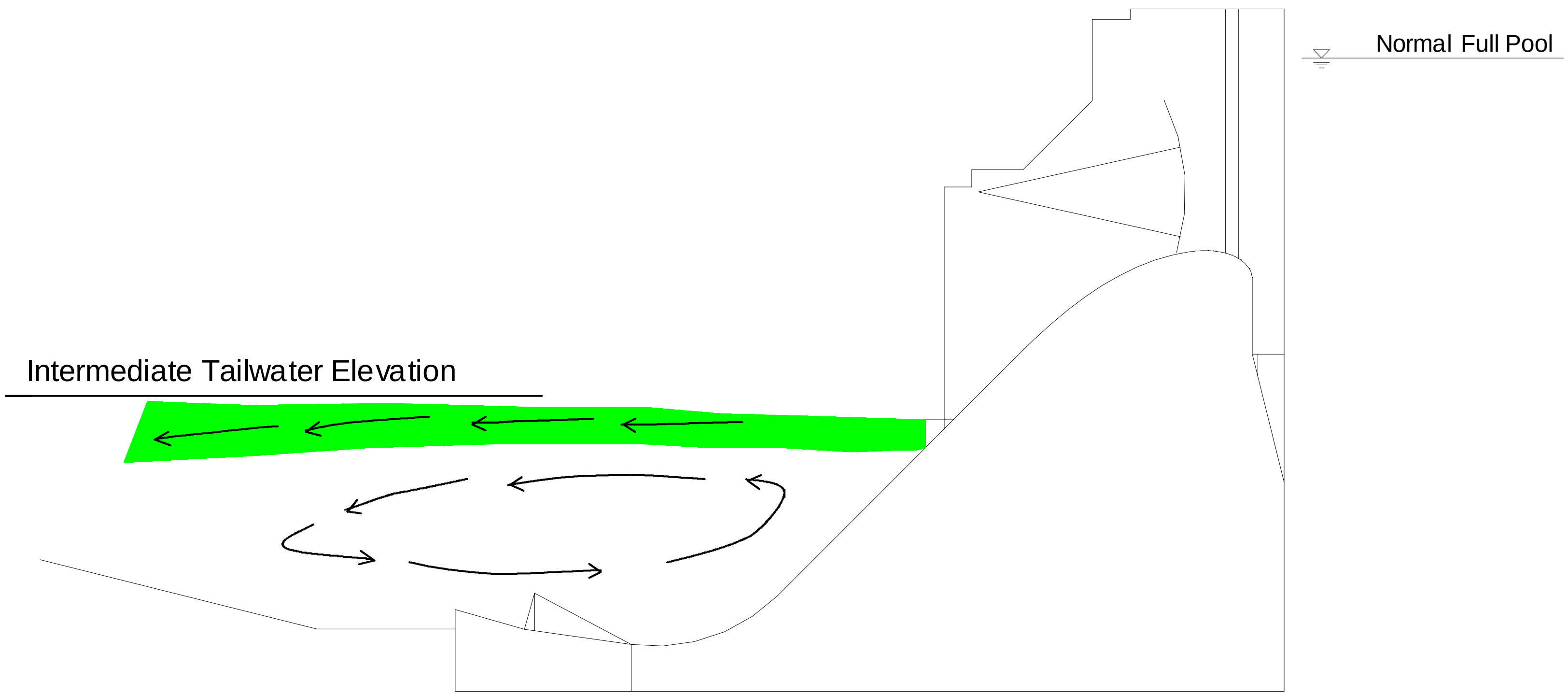


Figure B3. Skimming Surface Jet

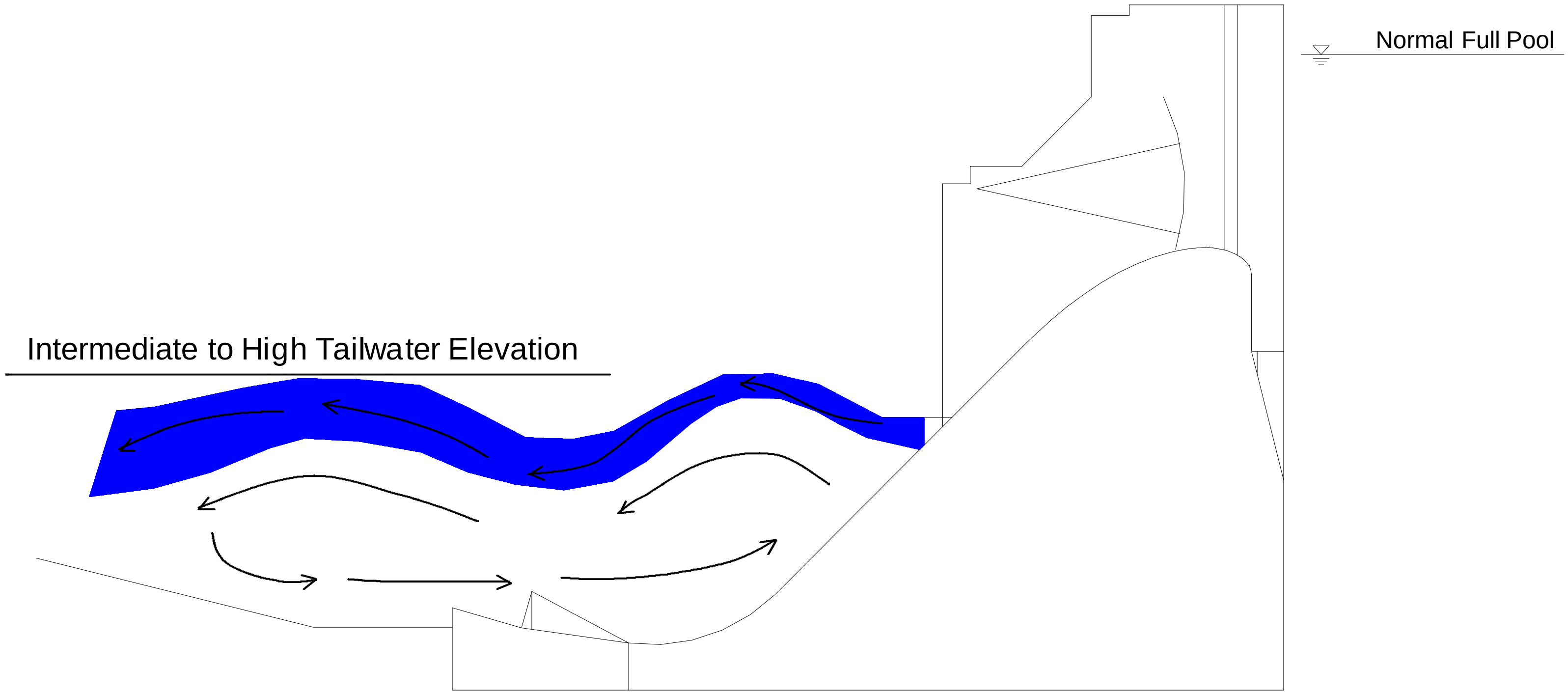


Figure B4. Undulating Surface Jet.

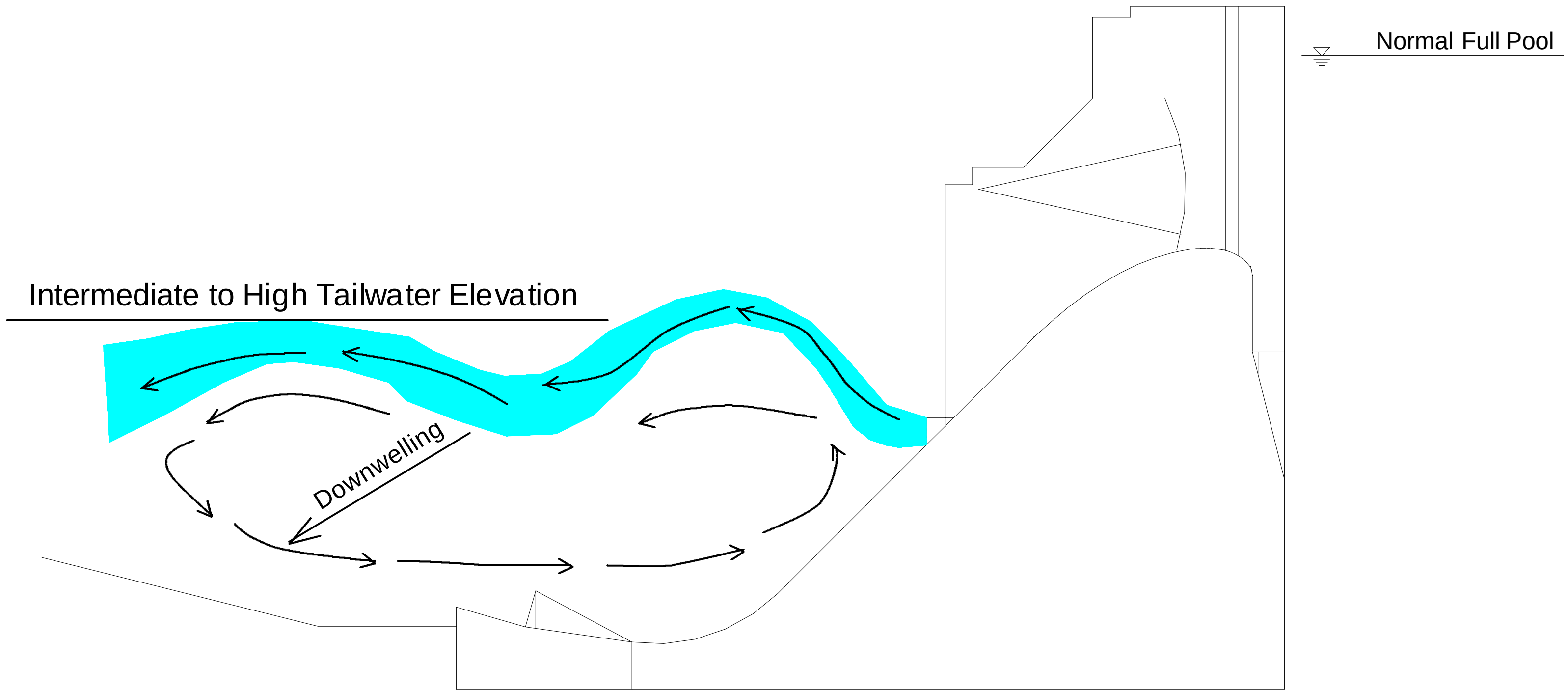


Figure B5. Ramped Surface Jet

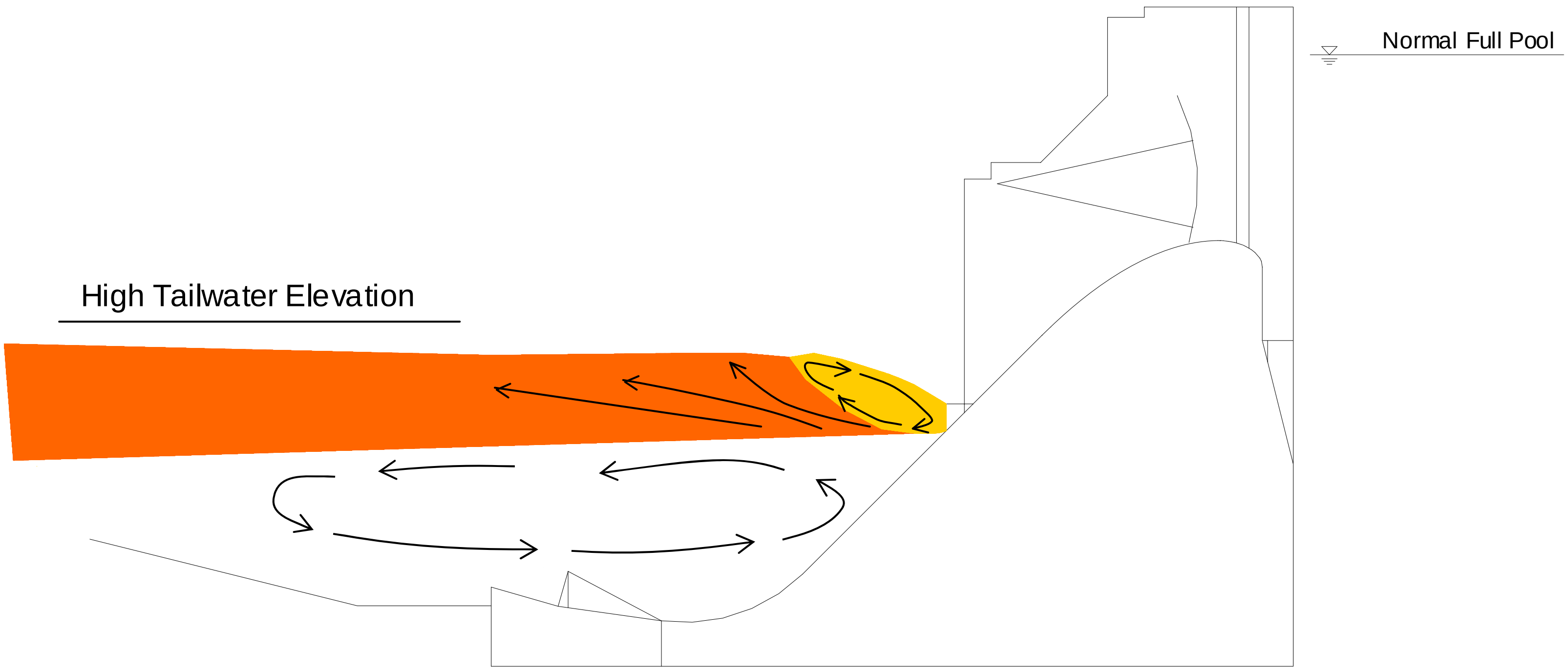


Figure B6. Surface Jump

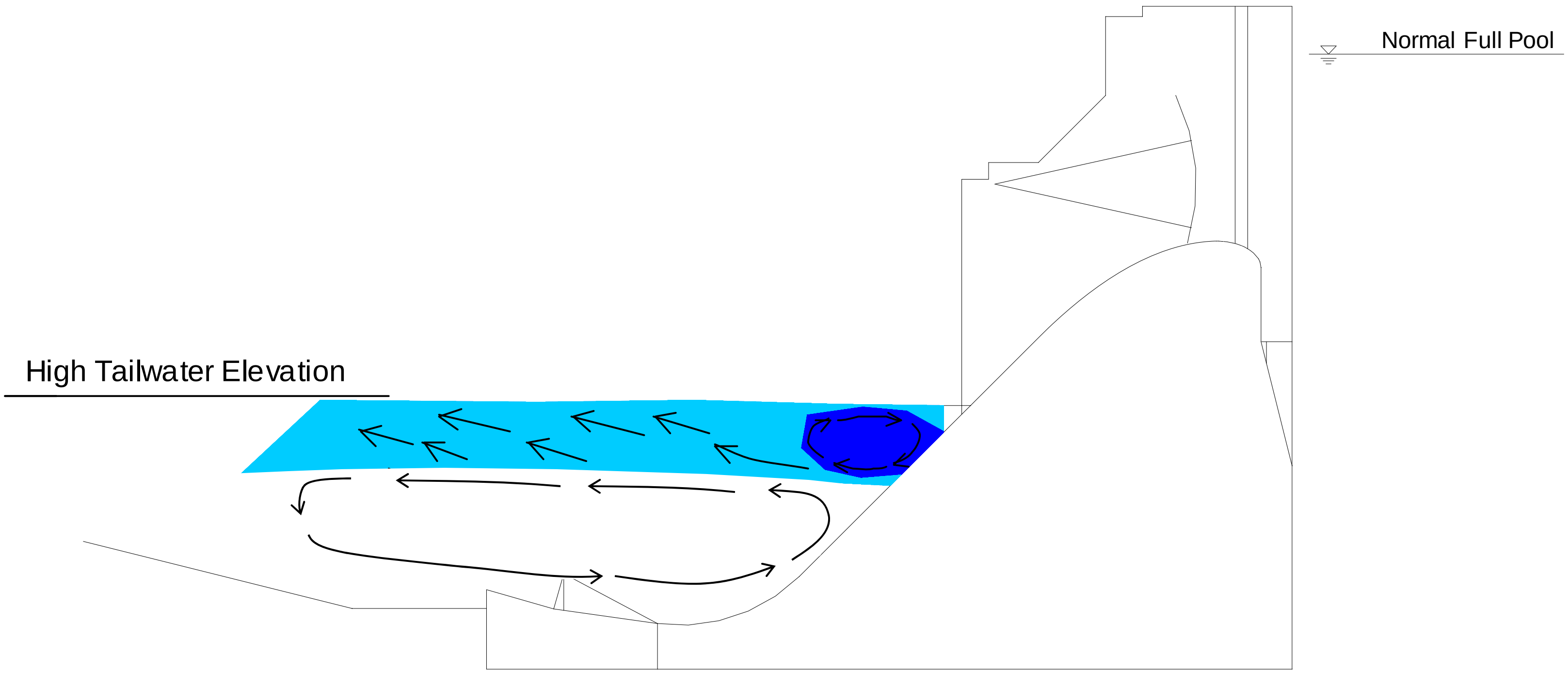


Figure B7. Submerged Surface Jump

Figure C1. Plunging Flow. Type I Deflector. Gate Opening – 2 ft, Discharge – 4559 cfs/bay, Pool El – 638, Tailwater El - 532

Figure C2. Skimming Surface Jet. Type I Deflector. Gate Opening – 2 ft, Discharge – 4559 cfs/bay, Pool El – 638, Tailwater El - 534

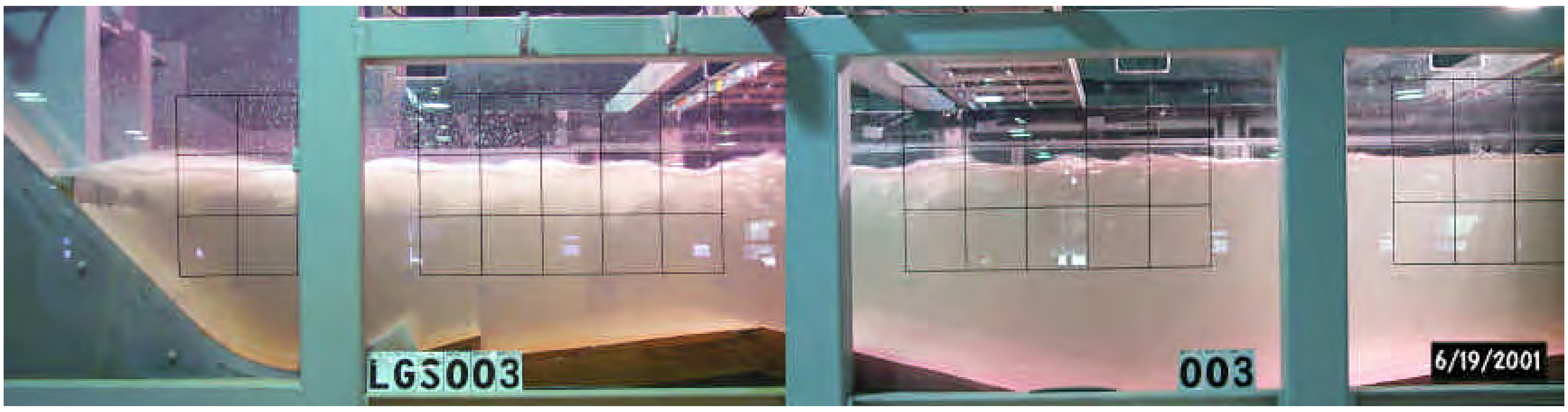


Figure C3. Skimming Surface Jet. Type I Deflector. Gate Opening – 2 ft, Discharge – 4559 cfs/bay, Pool El – 638, Tailwater El - 536

Figure C4. Skimming Surface Jet. Type I Deflector. Gate Opening – 2 ft, Discharge – 4559 cfs/bay, Pool El – 638, Tailwater El - 538

Figure C5. Undulating Surface Jet. Type I Deflector. Gate Opening – 2 ft, Discharge – 4559 cfs/bay, Pool El – 638, Tailwater El - 540

Figure C6. Ramped Surface Jet. Type I Deflector. Gate Opening – 2 ft, Discharge – 4559 cfs/bay, Pool El – 638, Tailwater El - 542

Figure C7. Surface Jump. Type I Deflector. Gate Opening – 2 ft, Discharge – 4559 cfs/bay, Pool El – 638, Tailwater El - 544

Figure C8. Submerged Surface Jump. Type I Deflector. Gate Opening – 2 ft, Discharge – 4559 cfs/bay, Pool El – 638, Tailwater El - 547

Figure C9. Plunging Flow. Type I Deflector. Gate Opening – 4 ft, Discharge – 8597 cfs/bay, Pool El – 638, Tailwater El - 532

Figure C10. Unstable Plunging Jet. Type I Deflector. Gate Opening – 4 ft, Discharge – 8597 cfs/bay, Pool El – 638, Tailwater El - 534

Figure C11. Skimming Surface Jet. Type I Deflector. Gate Opening – 4 ft, Discharge – 8597 cfs/bay, Pool El – 638, Tailwater El - 536

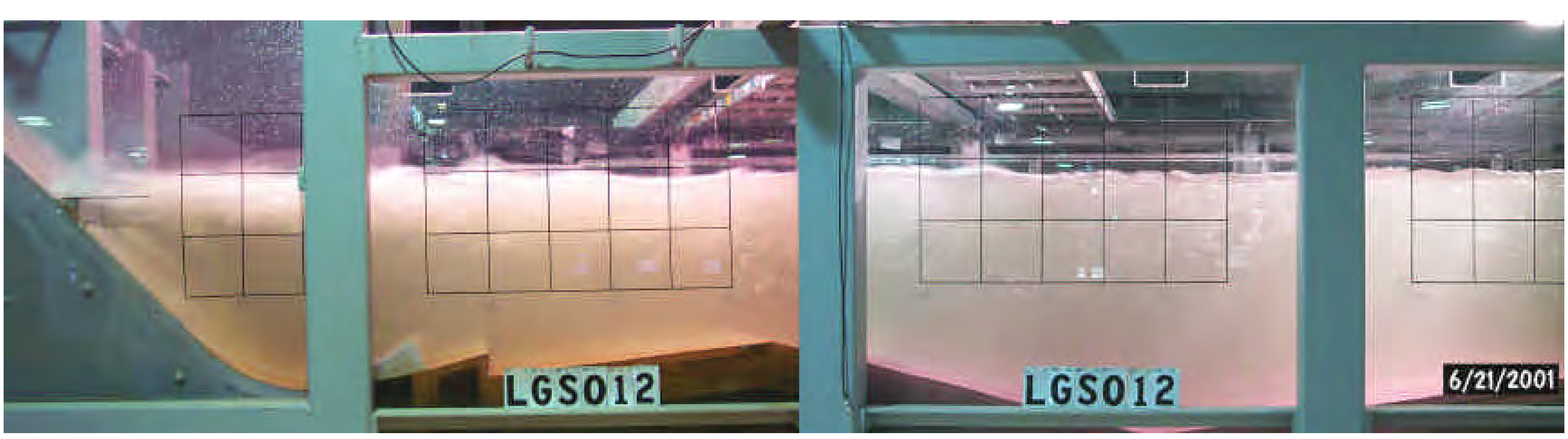


Figure C12. Skimming Surface Jet. Type I Deflector. Gate Opening – 4 ft, Discharge – 8597 cfs/bay, Pool El – 638, Tailwater El - 538

Figure C13. Skimming Surface Jet. Type I Deflector. Gate Opening – 4 ft, Discharge – 8597 cfs/bay, Pool El – 638, Tailwater El – 540

Figure C14. Undulating Surface Jet. Type I Deflector. Gate Opening – 4 ft, Discharge – 8597 cfs/bay, Pool El – 638, Tailwater El - 542

Figure C15. Undulating Surface Jet. Type I Deflector. Gate Opening – 4 ft, Discharge – 8597 cfs/bay, Pool El – 638, Tailwater El - 544

Figure C16. Surface Jump. Type I Deflector. Gate Opening – 4 ft, Discharge – 8597 cfs/bay, Pool El – 638, Tailwater El - 547

Figure C17. Plunging Flow. Type I Deflector. Gate Opening – 5 ft, Discharge – 9847 cfs/bay, Pool El – 638, Tailwater El - 532

Figure C18. Unstable Plunging Jet. Type I Deflector. Gate Opening – 5 ft, Discharge – 9847 cfs/bay, Pool El – 638, Tailwater El - 536

Figure C19. Skimming Surface Jet. Type I Deflector. Gate Opening – 5 ft, Discharge – 9847 cfs/bay, Pool El – 638, Tailwater El - 538

Figure C20. Skimming Surface Jet. Type I Deflector. Gate Opening – 5 ft, Discharge – 9847 cfs/bay, Pool El – 638, Tailwater El - 540

Figure C21. Undulating Surface Jet. Type I Deflector. Gate Opening – 5 ft, Discharge – 9847 cfs/bay, Pool El – 638, Tailwater El - 542

Figure C22. Undulating Surface Jet. Type I Deflector. Gate Opening – 5 ft, Discharge – 9847 cfs/bay, Pool El – 638, Tailwater El - 544

Figure C23. Ramped Surface Jet. Type I Deflector. Gate Opening – 5 ft, Discharge – 9847 cfs/bay, Pool El – 638, Tailwater El – 547

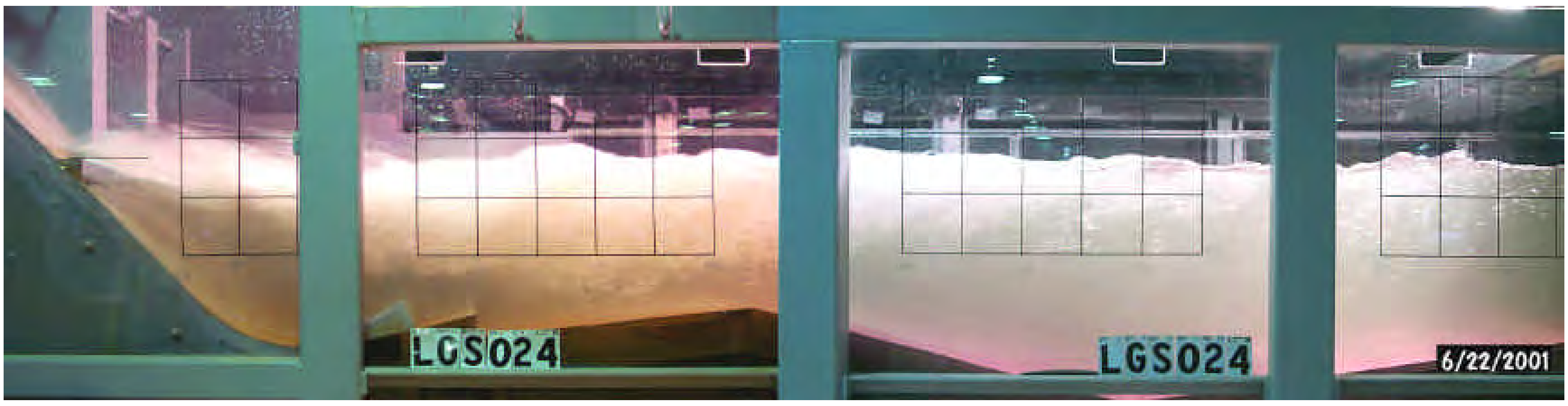


Figure C24. Plunging Flow. Type I Deflector. Gate Opening – 6 ft, Discharge – 12121 cfs/bay, Pool El – 638, Tailwater El – 532

Figure C25. Unstable Plunging Jet. Type I Deflector. Gate Opening – 6 ft, Discharge – 12121 cfs/bay, Pool El – 638, Tailwater El – 536

Figure C26. Skimming Surface Jet. Type I Deflector. Gate Opening – 6 ft, Discharge – 12121 cfs/bay, Pool El – 638, Tailwater El – 538

Figure C27. Skimming Surface Jet. Type I Deflector. Gate Opening – 6 ft, Discharge – 12121 cfs/bay, Pool El – 638, Tailwater El – 540

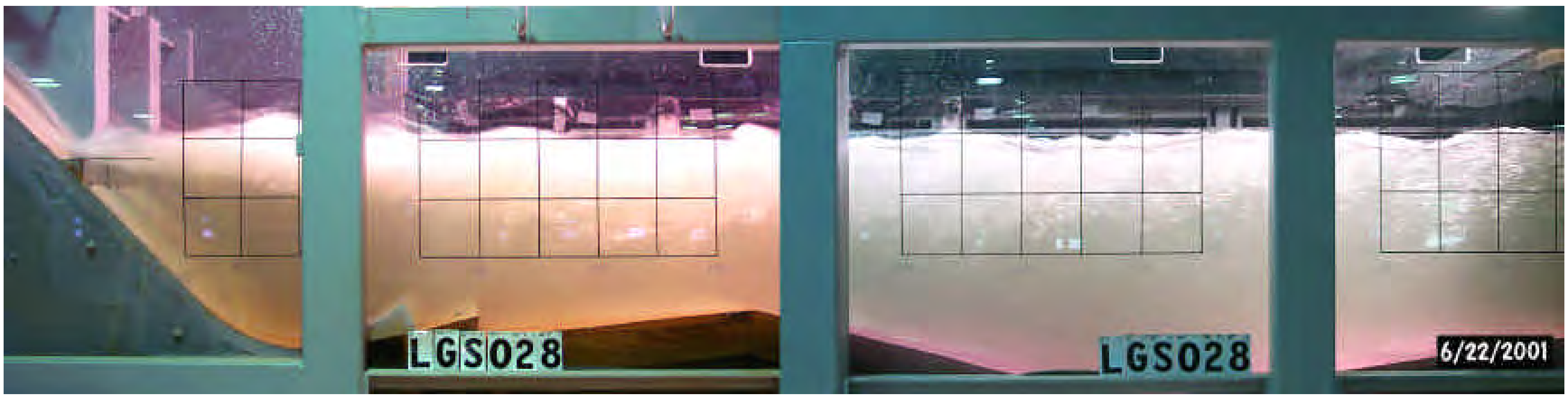


Figure C28. Skimming Surface Jet. Type I Deflector. Gate Opening – 6 ft, Discharge – 12121 cfs/bay, Pool El – 638, Tailwater El – 542

Figure C29. Undulating Surface Jet. Type I Deflector. Gate Opening – 6 ft, Discharge – 12121 cfs/bay, Pool El – 638, Tailwater El – 544

Figure C30. Undulating Surface Jet. Type I Deflector. Gate Opening – 6 ft, Discharge – 12121 cfs/bay, Pool El – 638, Tailwater El – 547

Figure C31. Plunging Flow. Type I Deflector. Gate Opening – 8 ft, Discharge – 15960 cfs/bay, Pool El – 638, Tailwater El – 532

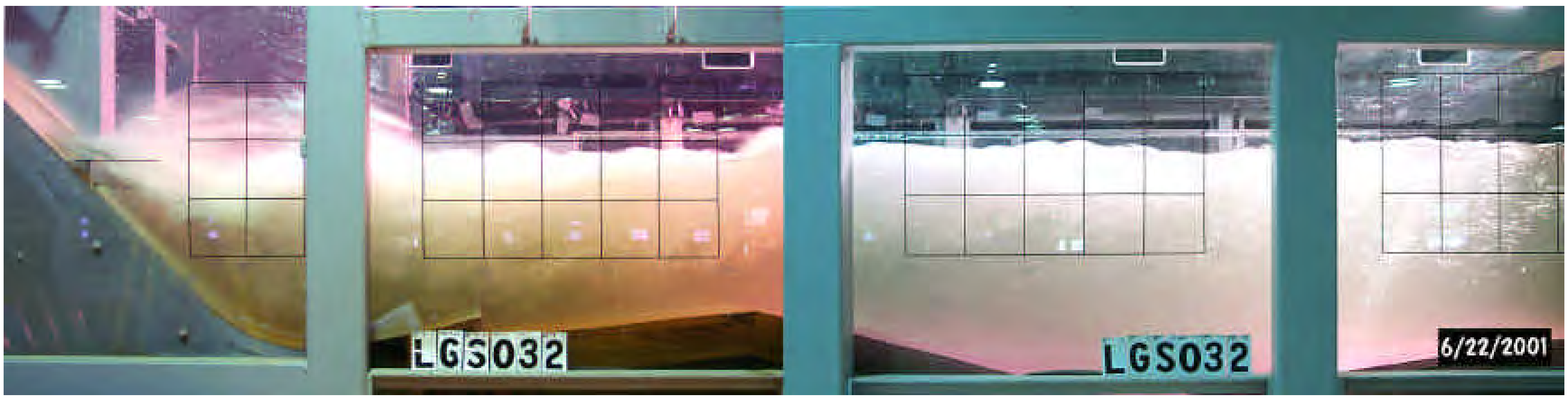


Figure C32. Plunging Flow. Type I Deflector. Gate Opening – 8 ft, Discharge – 15960 cfs/bay, Pool El – 638, Tailwater El – 536

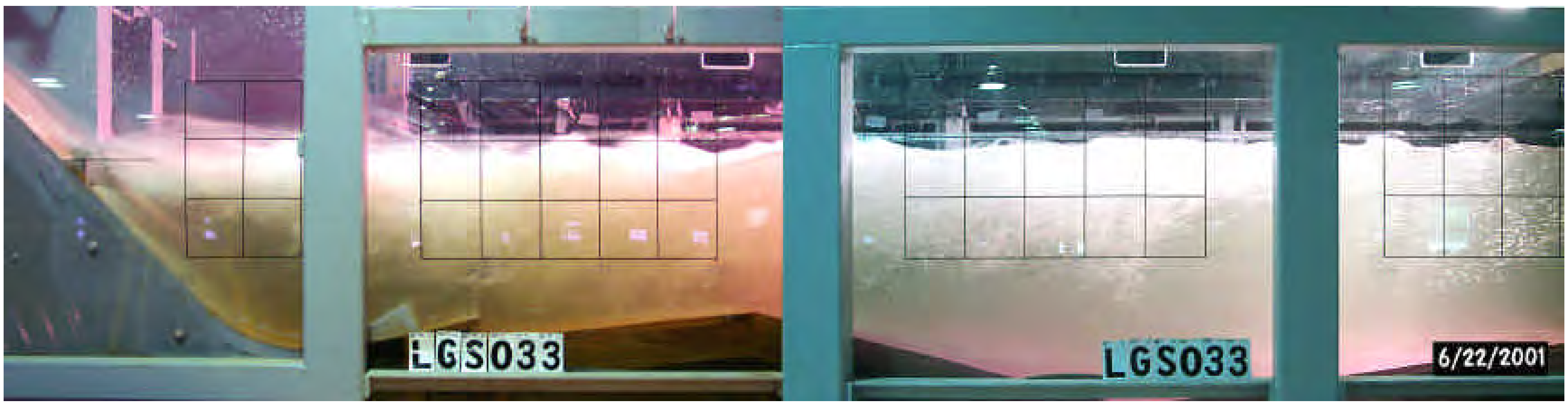


Figure C33. Plunging Flow. Type I Deflector. Gate Opening – 8 ft, Discharge – 15960 cfs/bay, Pool El – 638, Tailwater El – 538

Figure C34. Plunging Flow. Type I Deflector. Gate Opening – 8 ft, Discharge – 15960 cfs/bay, Pool El – 638, Tailwater El – 540

Figure C35. Skimming Surface Jet. Type I Deflector. Gate Opening – 8 ft, Discharge – 15960 cfs/bay, Pool El – 638, Tailwater El – 542

Figure C36. Skimming Surface Jet. Type I Deflector. Gate Opening – 8 ft, Discharge – 15960 cfs/bay, Pool El – 638, Tailwater El – 544

Figure C37. Skimming Surface Jet. Type I Deflector. Gate Opening – 8 ft, Discharge – 15960 cfs/bay, Pool El – 638, Tailwater El – 547

Figure C38. Skimming Surface Jet. Type I Deflector. Gate Opening – 10 ft, Discharge – 19583 cfs/bay, Pool El – 638, Tailwater El – 547

Figure C39. Plunging Flow. Type I Deflector. Gate Opening – 10 ft, Discharge – 19583 cfs/bay, Pool El – 638, Tailwater El – 544

Figure C40. Plunging Flow. Type I Deflector. Gate Opening – 10 ft, Discharge – 19583 cfs/bay, Pool El – 638, Tailwater El – 542

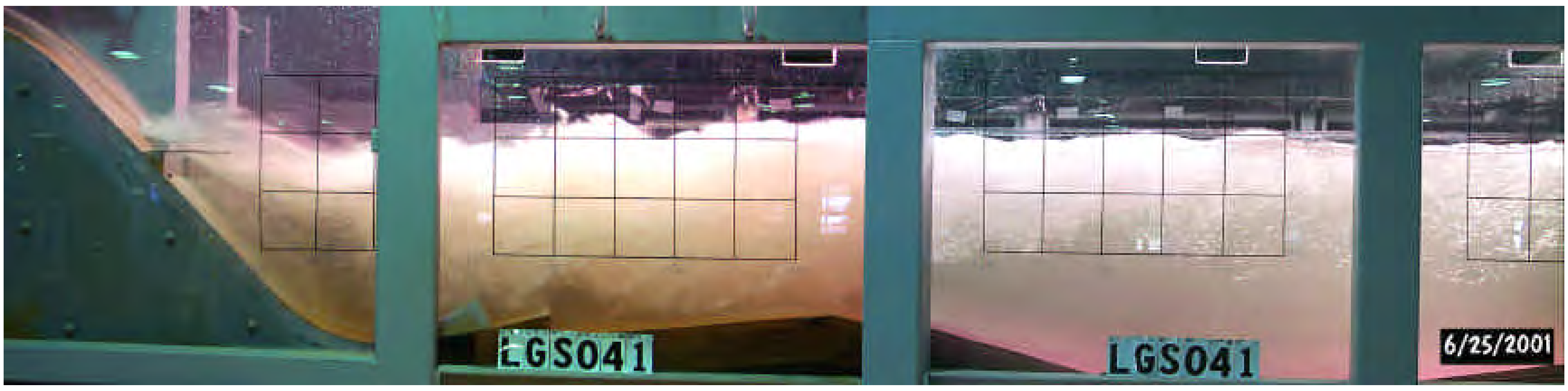


Figure C41. Plunging Flow. Type I Deflector. Gate Opening – 10 ft, Discharge – 19583 cfs/bay, Pool El – 638, Tailwater El – 540

Figure C42. Plunging Flow. Type Ib Deflector. Gate Opening – 2 ft, Discharge – 4559 cfs/bay, Pool El – 638, Tailwater El – 532

Figure C43. Skimming Surface Jet. Type Ib Deflector. Gate Opening – 2 ft, Discharge – 4559 cfs/bay, Pool El – 638, Tailwater El – 534

Figure C44. Undulating Surface Jet. Type Ib Deflector. Gate Opening – 2 ft, Discharge – 4559 cfs/bay, Pool El – 638, Tailwater El – 536

Figure C45. Undulating Surface Jet. Type Ib Deflector. Gate Opening – 2 ft, Discharge – 4559 cfs/bay, Pool El – 638, Tailwater El – 538

Figure C46. Undulating Surface Jet. Type Ib Deflector. Gate Opening – 2 ft, Discharge – 4559 cfs/bay, Pool El – 638, Tailwater El – 540

Figure C47. Ramped Surface Jet. Type Ib Deflector. Gate Opening – 2 ft, Discharge – 4559 cfs/bay, Pool El – 638, Tailwater El – 542

Figure C48. Surface Jump. Type Ib Deflector. Gate Opening – 2 ft, Discharge – 4559 cfs/bay, Pool El – 638, Tailwater El – 544

Figure C49. Submerged Surface Jump. Type Ib Deflector. Gate Opening – 2 ft, Discharge – 4559 cfs/bay, Pool El – 638, Tailwater El – 547

Figure C50. Plunging Flow. Type Ib Deflector. Gate Opening – 4 ft, Discharge – 8597 cfs/bay, Pool El – 638, Tailwater El – 532

Figure C51. Plunging Flow. Type Ib Deflector. Gate Opening – 4 ft, Discharge – 8597 cfs/bay, Pool El – 638, Tailwater El – 534

Figure C52. Skimming Surface Jet. Type Ib Deflector. Gate Opening – 4 ft, Discharge – 8597 cfs/bay, Pool El – 638, Tailwater El – 536

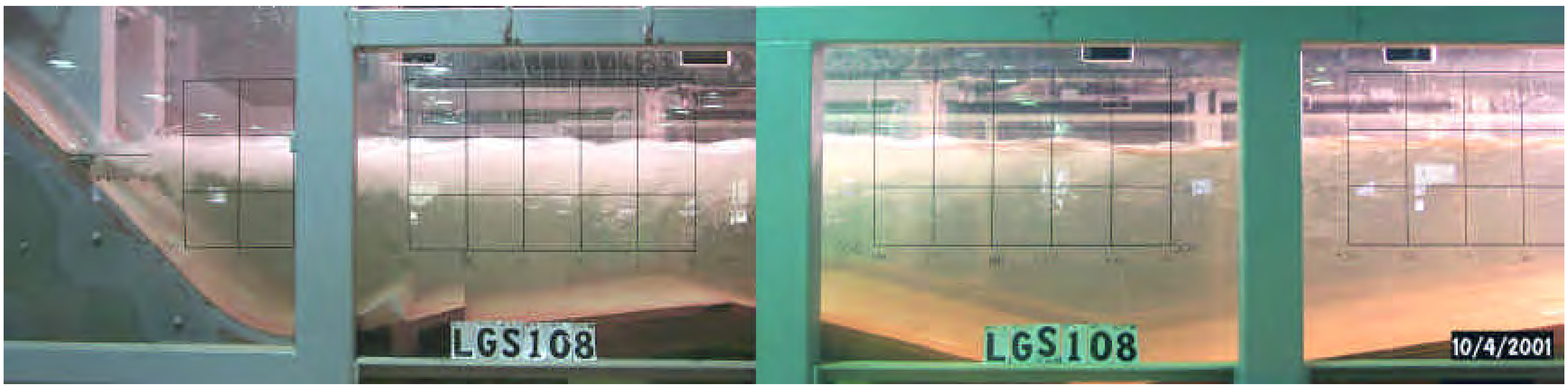


Figure C53. Skimming Surface Jet. Type Ib Deflector. Gate Opening – 4 ft, Discharge – 8597 cfs/bay, Pool El – 638, Tailwater El – 538

Figure C54. Undulating Surface Jet. Type Ib Deflector. Gate Opening – 4 ft, Discharge – 8597 cfs/bay, Pool El – 638, Tailwater El – 540

Figure C55. Undulating Surface Jet. Type Ib Deflector. Gate Opening – 4 ft, Discharge – 8597 cfs/bay, Pool El – 638, Tailwater El – 542

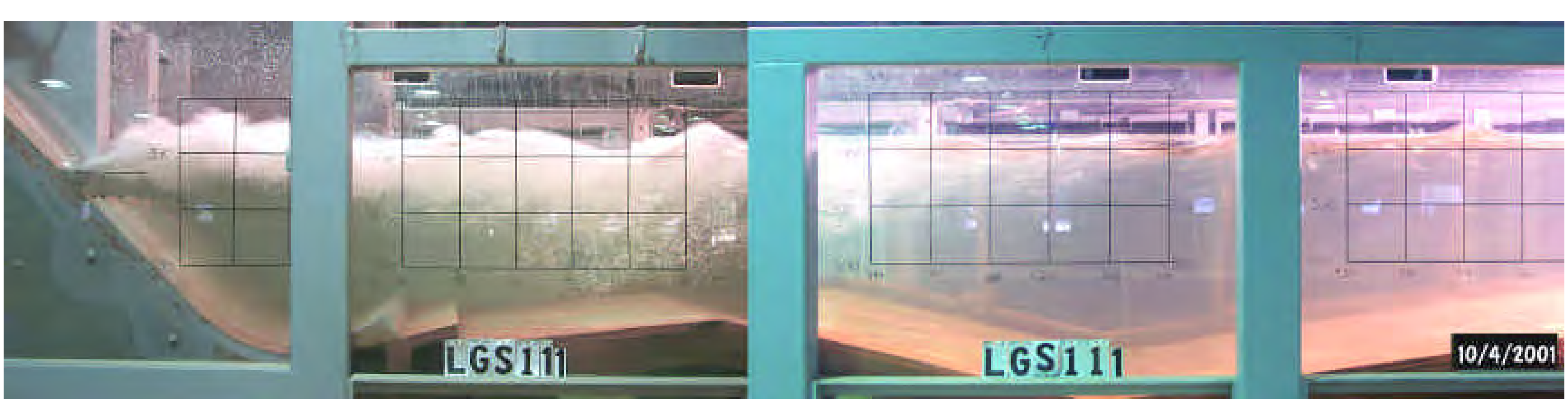


Figure C56. Ramped Surface Jet. Type Ib Deflector. Gate Opening – 4 ft, Discharge – 8597 cfs/bay, Pool El – 638, Tailwater El – 544

Figure C57. Surface Jump. Type Ib Deflector. Gate Opening – 4 ft, Discharge – 8597 cfs/bay, Pool El – 638, Tailwater El – 547

Figure C58. Surface Jump. Type Ib Deflector. Gate Opening – 5 ft, Discharge – 9847 cfs/bay, Pool El – 638, Tailwater El – 547

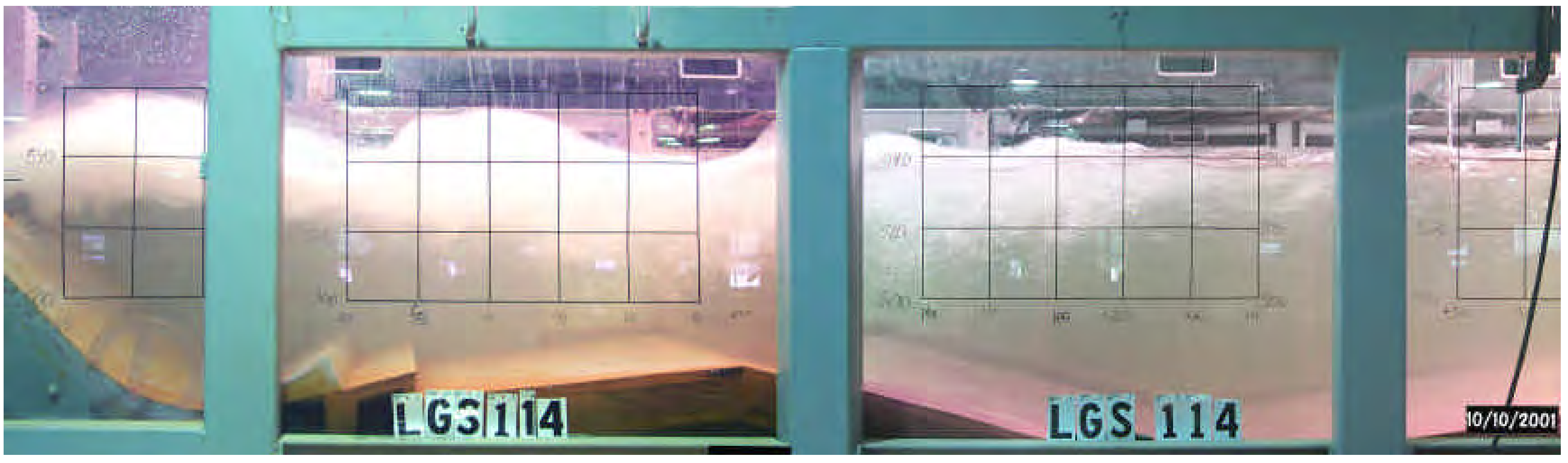


Figure C59. Ramped Surface Jet. Type Ib Deflector. Gate Opening – 5 ft, Discharge – 9847 cfs/bay, Pool El – 638, Tailwater El – 544

Figure C60. Undulating Surface Jet. Type Ib Deflector. Gate Opening – 5 ft, Discharge – 9847 cfs/bay, Pool El – 638, Tailwater El – 542

Figure C61. Skimming Surface Jet. Type Ib Deflector. Gate Opening – 5 ft, Discharge – 9847 cfs/bay, Pool El – 638, Tailwater El – 540

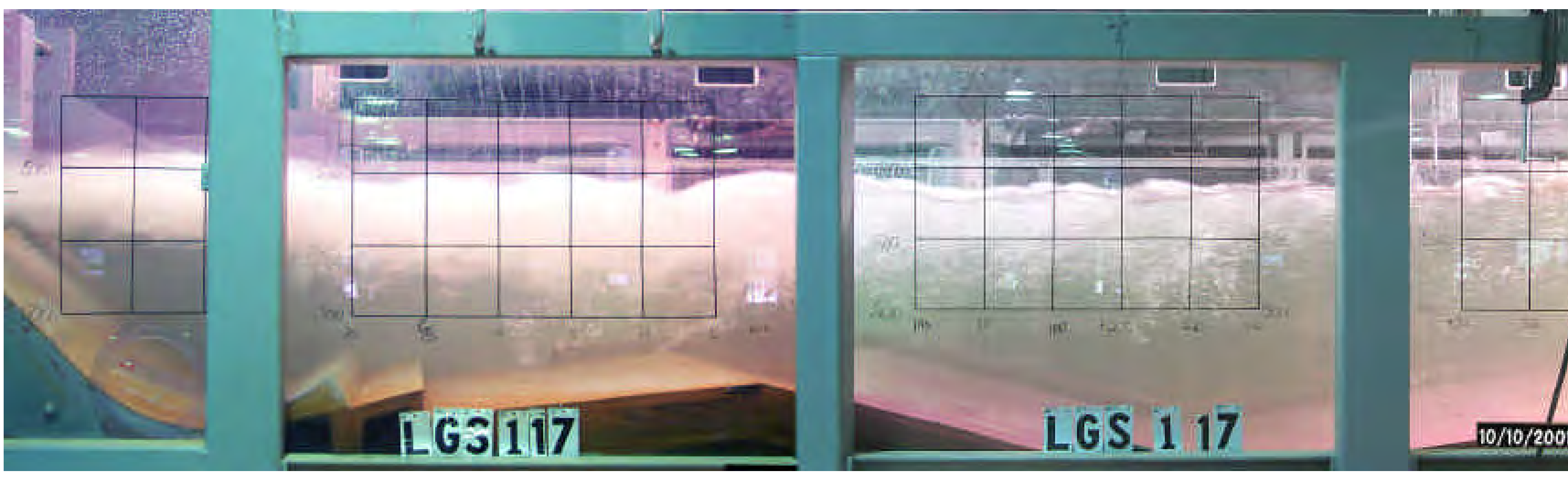


Figure C62. Skimming Surface Jet. Type Ib Deflector. Gate Opening – 5 ft, Discharge – 9847 cfs/bay, Pool El – 638, Tailwater El – 538

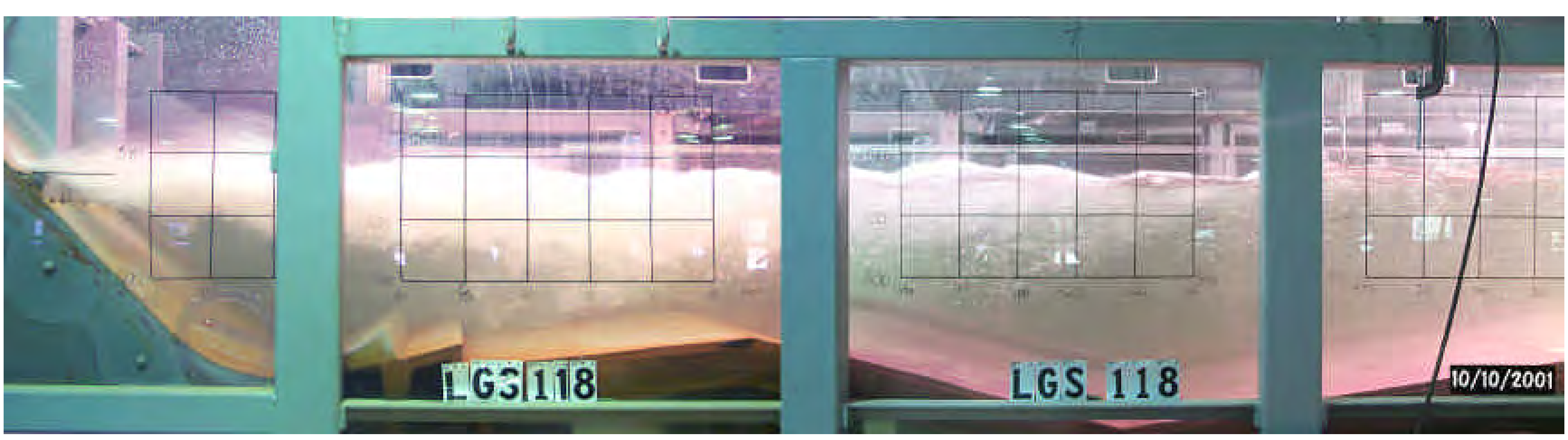


Figure C63. Plunging Flow. Type Ib Deflector. Gate Opening – 5 ft, Discharge – 9847 cfs/bay, Pool El – 638, Tailwater El – 536

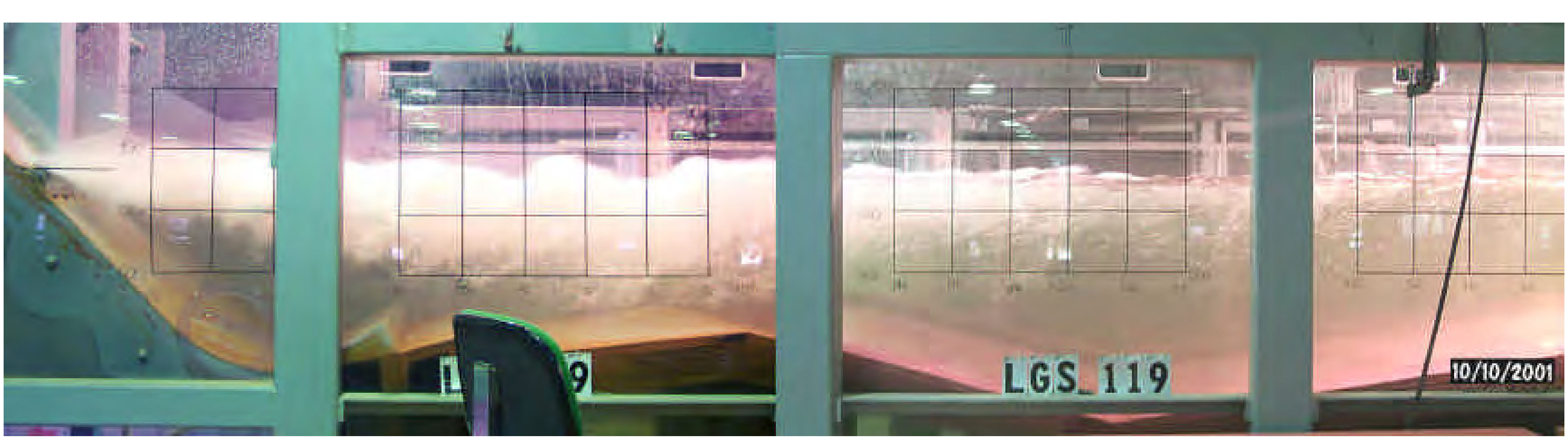


Figure C64. Plunging Flow. Type Ib Deflector. Gate Opening – 5 ft, Discharge – 9847 cfs/bay, Pool El – 638, Tailwater El – 534

Figure C65. Undulating Surface Jet. Type Ib Deflector. Gate Opening – 6 ft, Discharge – 12121 cfs/bay, Pool El – 638, Tailwater El – 547

Figure C66. Undulating Surface Jet. Type Ib Deflector. Gate Opening – 6 ft, Discharge – 12121 cfs/bay, Pool El – 638, Tailwater El – 545

Figure C67. Skimming Surface Jet. Type Ib Deflector. Gate Opening – 6 ft, Discharge – 12121 cfs/bay, Pool El – 638, Tailwater El – 543

Figure C68. Skimming Surface Jet. Type Ib Deflector. Gate Opening – 6 ft, Discharge – 12121 cfs/bay, Pool El – 638, Tailwater El – 541

Figure C69. Plunging Flow. Type Ib Deflector. Gate Opening – 6 ft, Discharge – 12121 cfs/bay, Pool El – 638, Tailwater El – 539

Figure C70. Plunging Flow. Type Ib Deflector. Gate Opening – 6 ft, Discharge – 12121 cfs/bay, Pool El – 638, Tailwater El – 537

Figure C71. Skimming Surface Jet. Type Ib Deflector. Gate Opening – 8 ft, Discharge – 15960 cfs/bay, Pool El – 638, Tailwater El – 547

Figure C72. Skimming Surface Jet. Type Ib Deflector. Gate Opening – 8 ft, Discharge – 15960 cfs/bay, Pool El – 638, Tailwater El – 545

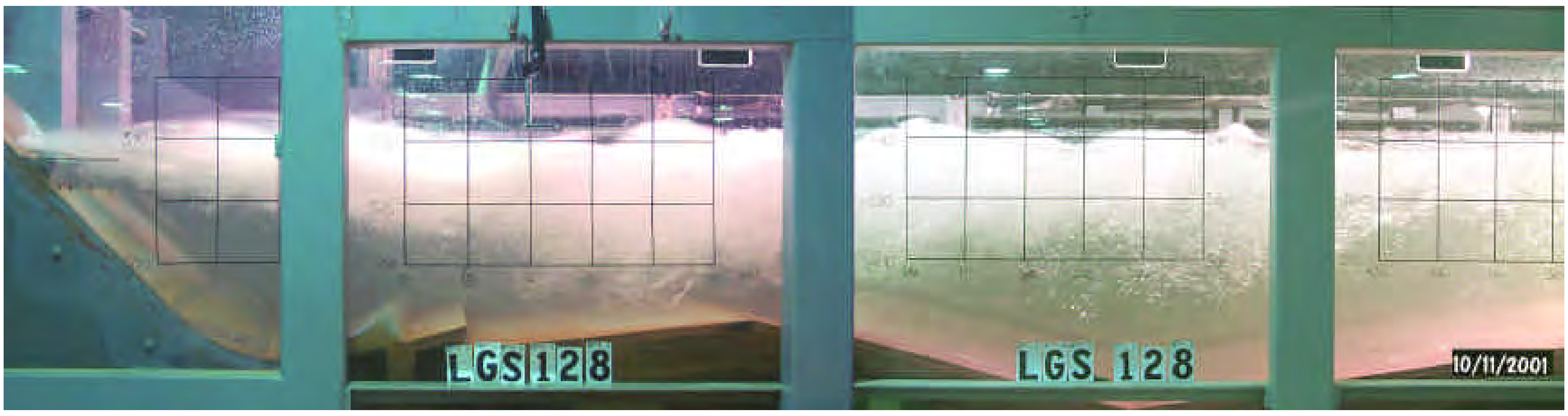


Figure C73. Plunging Flow. Type Ib Deflector. Gate Opening – 8 ft, Discharge – 15960 cfs/bay, Pool El – 638, Tailwater El – 543

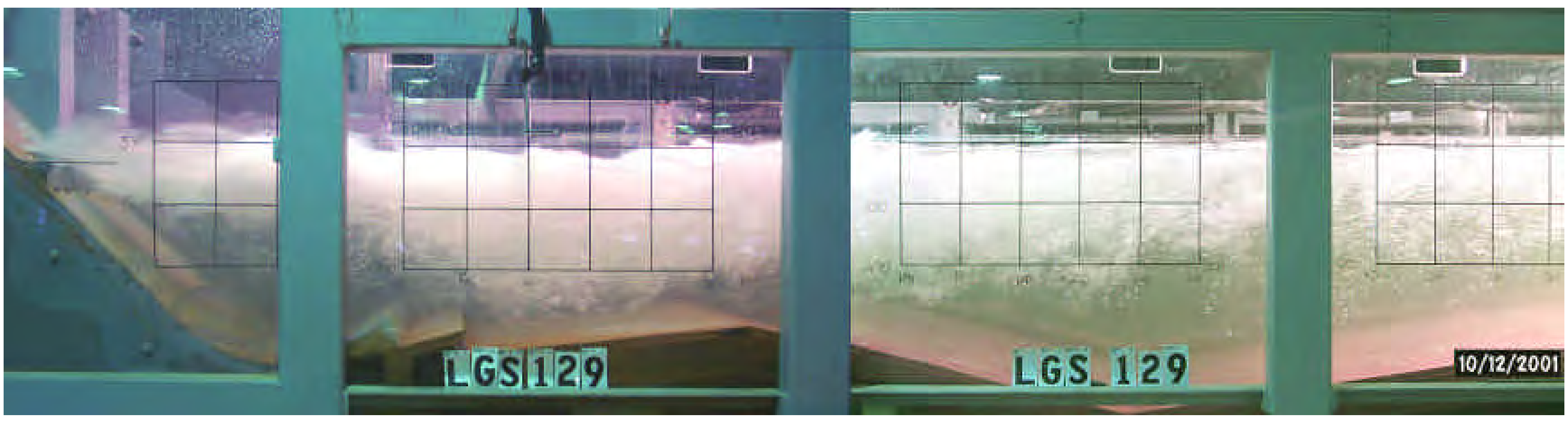


Figure C74. Plunging Flow. Type Ib Deflector. Gate Opening – 8 ft, Discharge – 15996 cfs/bay, Pool El – 638, Tailwater El – 541

Figure C75. Plunging Flow. Type Ib Deflector. Gate Opening – 8 ft, Discharge – 15996 cfs/bay, Pool El – 638, Tailwater El – 539

Figure C76. Plunging Flow. Type Ib Deflector. Gate Opening – 10 ft, Discharge – 19583 cfs/bay, Pool El – 638, Tailwater El – 547

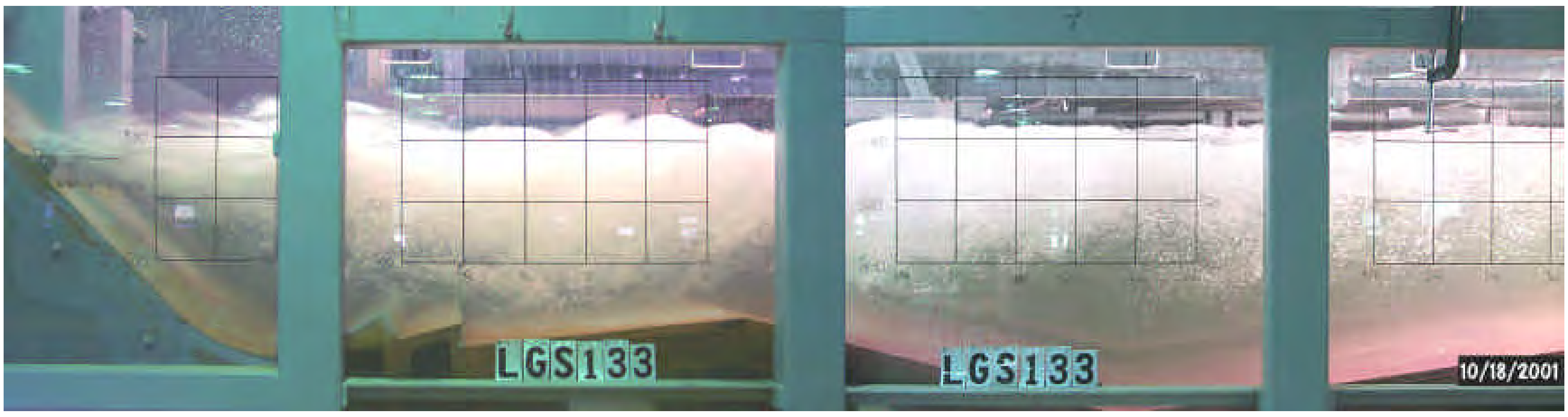


Figure C77. Plunging Flow. Type Ib Deflector. Gate Opening – 10 ft, Discharge – 19583 cfs/bay, Pool El – 638, Tailwater El – 545

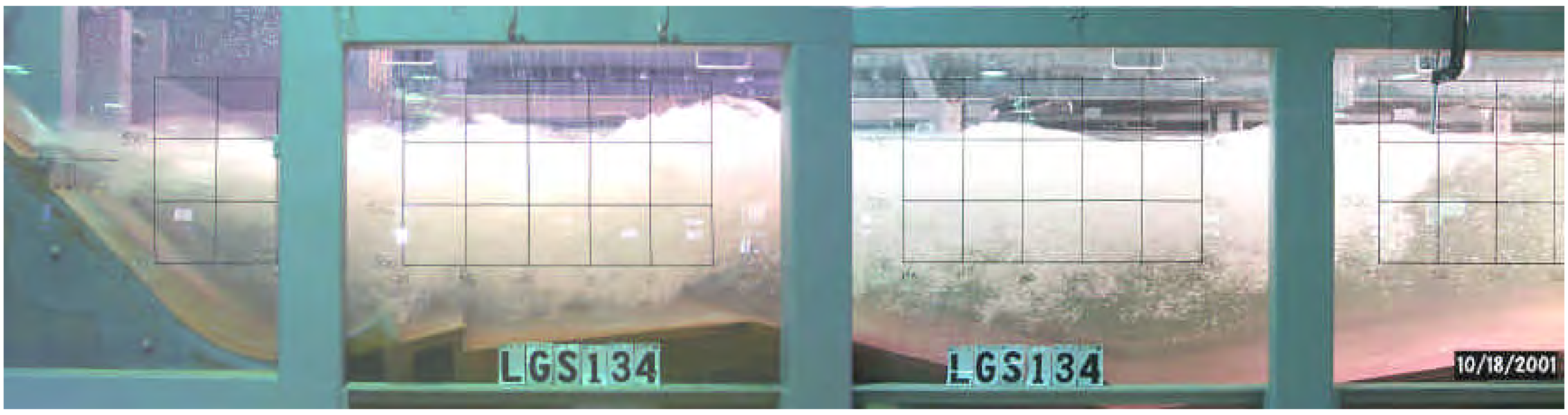


Figure C78. Plunging Flow. Type Ib Deflector. Gate Opening – 10 ft, Discharge – 19583 cfs/bay, Pool El – 638, Tailwater El – 543

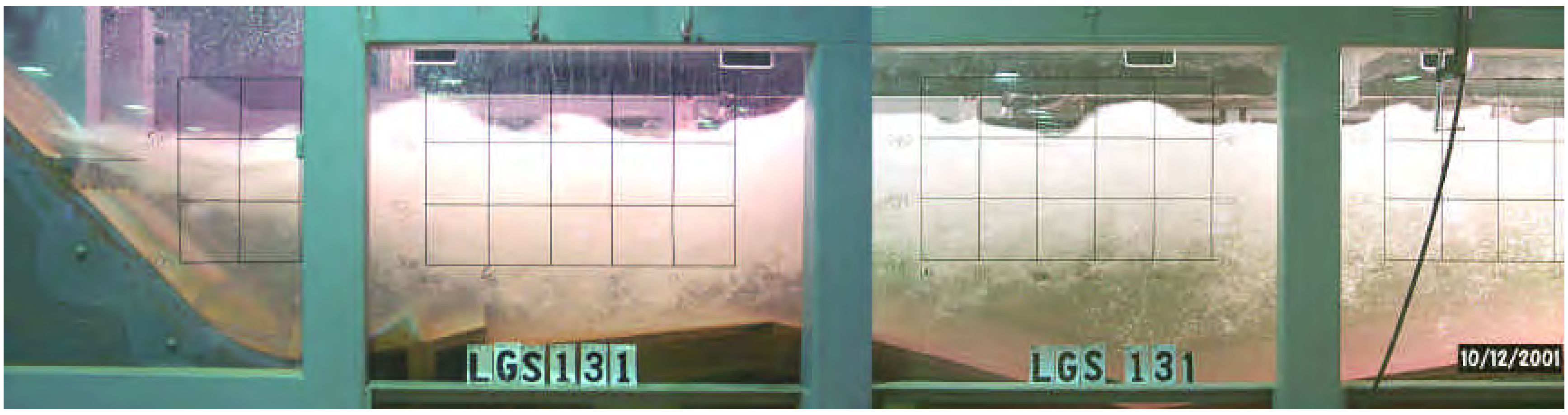


Figure C79. Plunging Flow. Type Ib Deflector. Gate Opening – 12 ft, Discharge – 23731 cfs/bay, Pool El – 638, Tailwater El – 547

Figure C80. Plunging Flow. Type II Deflector. Gate Opening – 12 ft, Discharge – 23731 cfs/bay, Pool El – 638, Tailwater El – 532

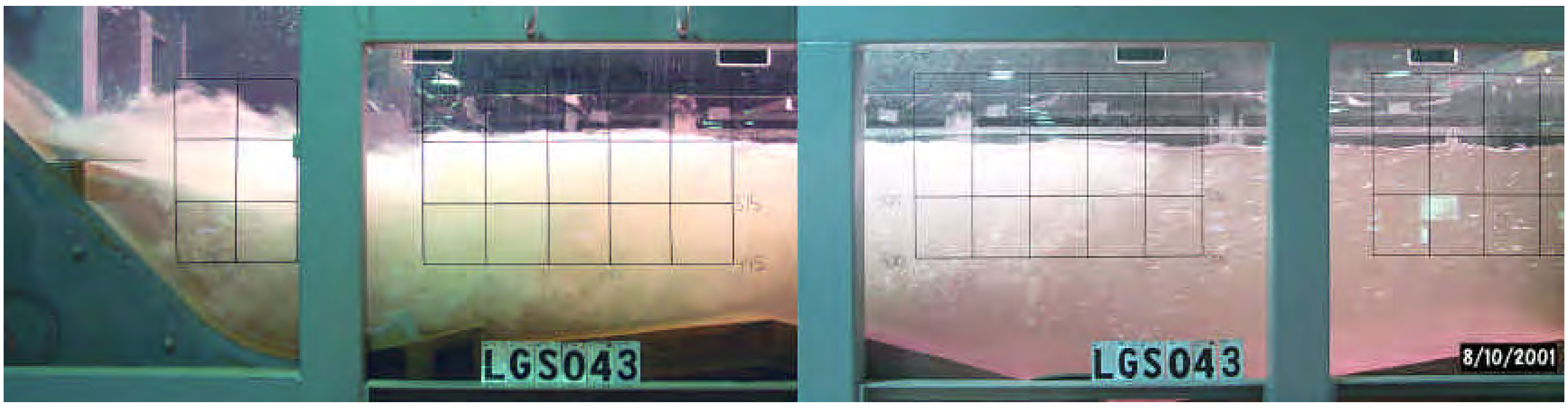


Figure C81. Plunging Flow. Type II Deflector. Gate Opening – 12 ft, Discharge – 23731 cfs/bay, Pool El – 638, Tailwater El – 536

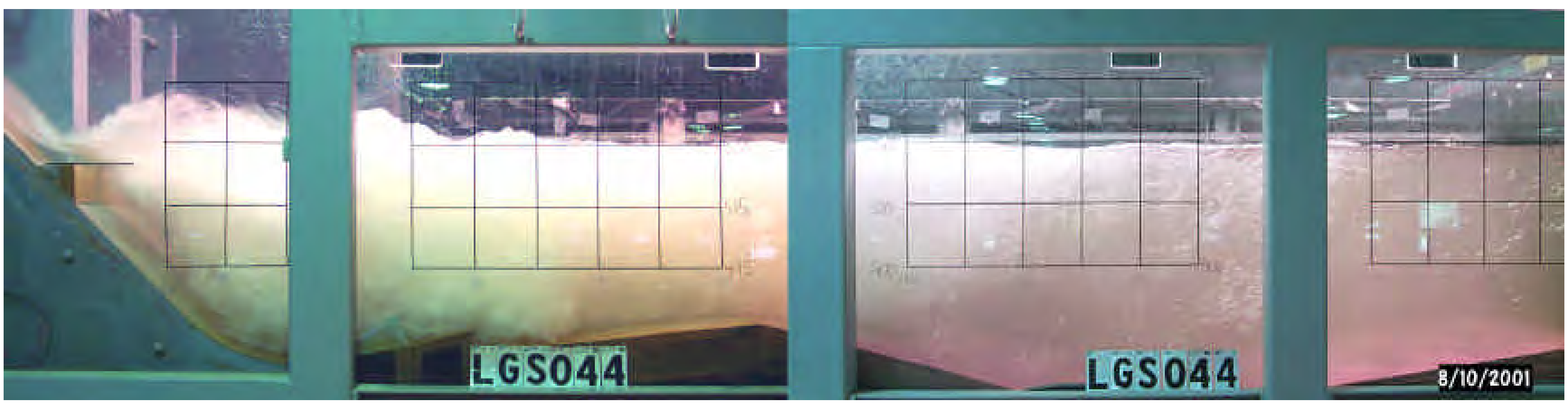


Figure C82. Plunging Flow. Type II Deflector. Gate Opening – 12 ft, Discharge – 23731 cfs/bay, Pool El – 638, Tailwater El – 538

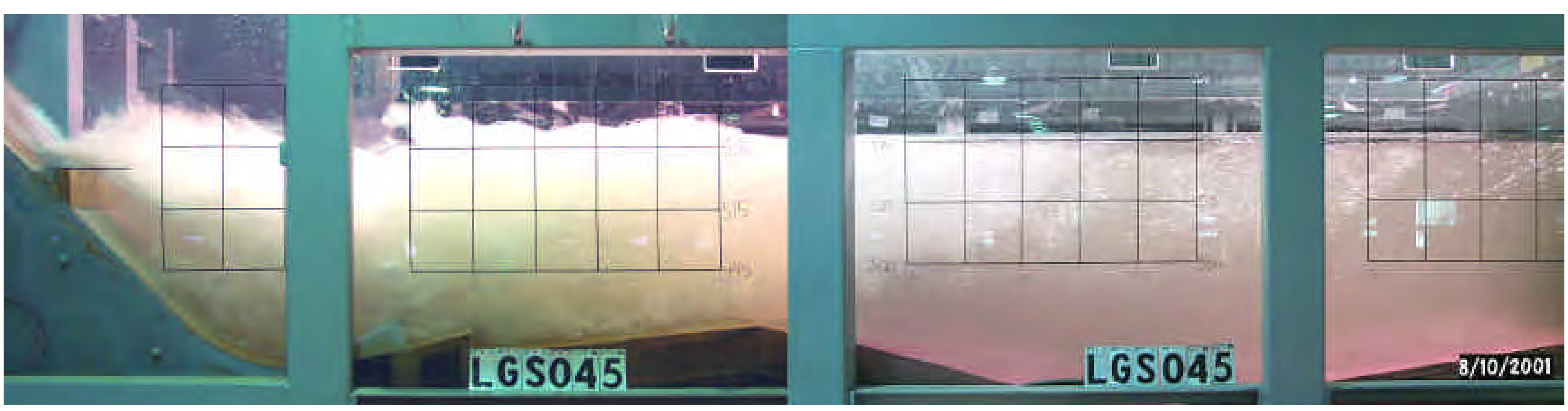


Figure C83. Plunging Flow. Type II Deflector. Gate Opening – 12 ft, Discharge – 23731 cfs/bay, Pool El – 638, Tailwater El – 540

Figure C84. Plunging Flow. Type II Deflector. Gate Opening – 12 ft, Discharge – 23731 cfs/bay, Pool El – 638, Tailwater El – 542

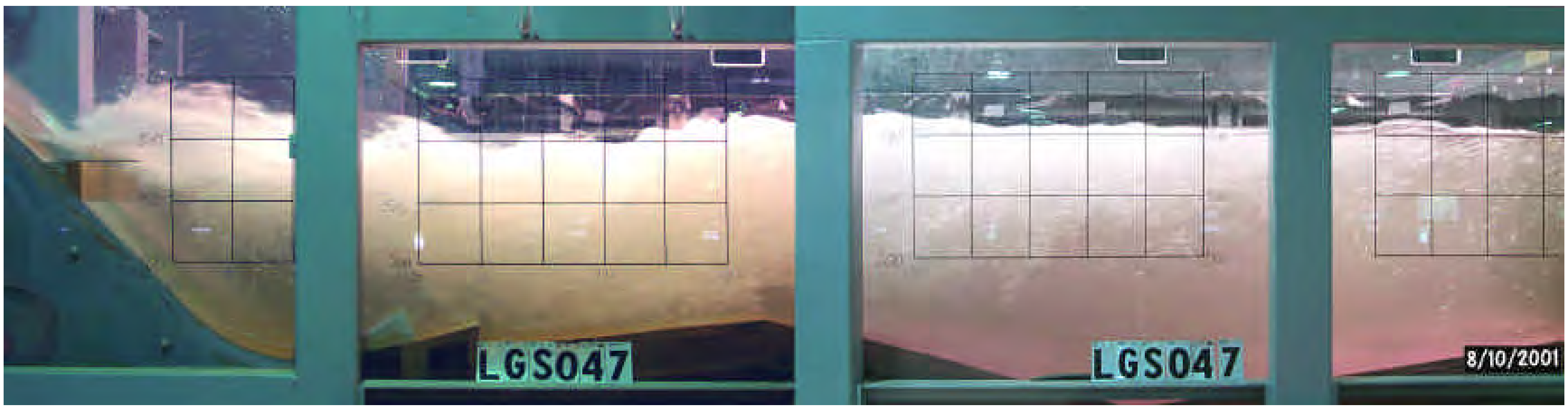


Figure C85. Plunging Flow. Type II Deflector. Gate Opening – 12 ft, Discharge – 23731 cfs/bay, Pool El – 638, Tailwater El – 544

Figure C86. Skimming Surface Jet. Type II Deflector. Gate Opening – 12 ft, Discharge – 23731 cfs/bay, Pool El – 638, Tailwater El – 550

Figure C87. Skimming Surface Jet. Type II Deflector. Gate Opening – 12 ft, Discharge – 23731 cfs/bay, Pool El – 638, Tailwater El – 547

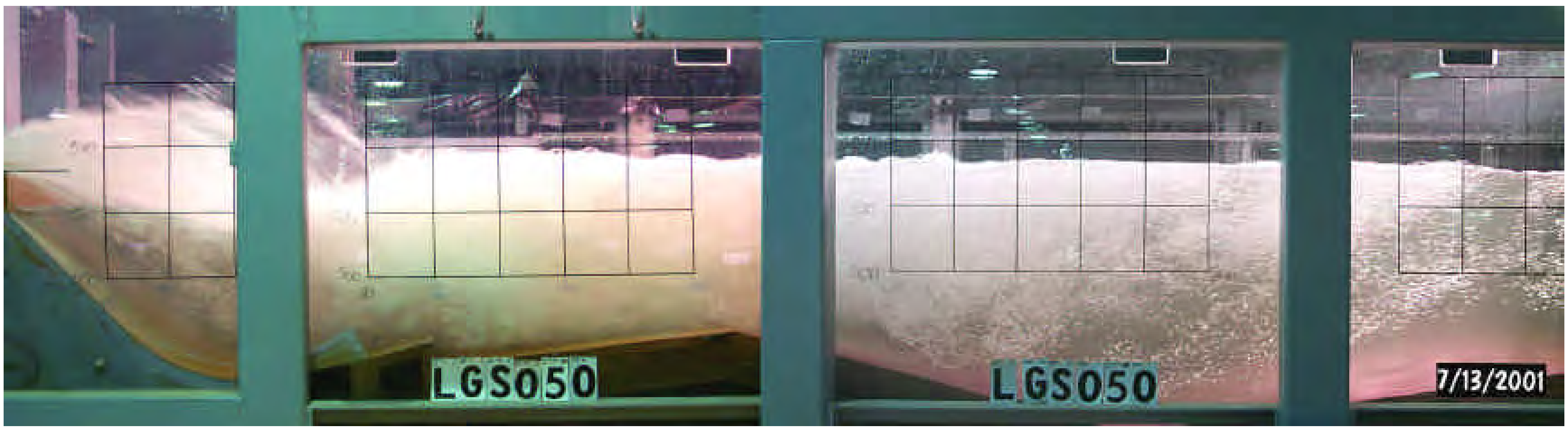


Figure C88. Plunging Flow. Type II Deflector. Gate Opening – 10 ft, Discharge – 19583 cfs/bay, Pool El – 639, Tailwater El – 532

Figure C89. Plunging Flow. Type II Deflector. Gate Opening – 10 ft, Discharge – 19583 cfs/bay, Pool El – 638, Tailwater El – 536

Figure C90. Plunging Flow. Type II Deflector. Gate Opening – 10 ft, Discharge – 19583 cfs/bay, Pool El – 639, Tailwater El – 540

Figure C91. Skimming Surface Jet. Type II Deflector. Gate Opening – 10 ft, Discharge – 19583 cfs/bay, Pool El – 639, Tailwater El – 542

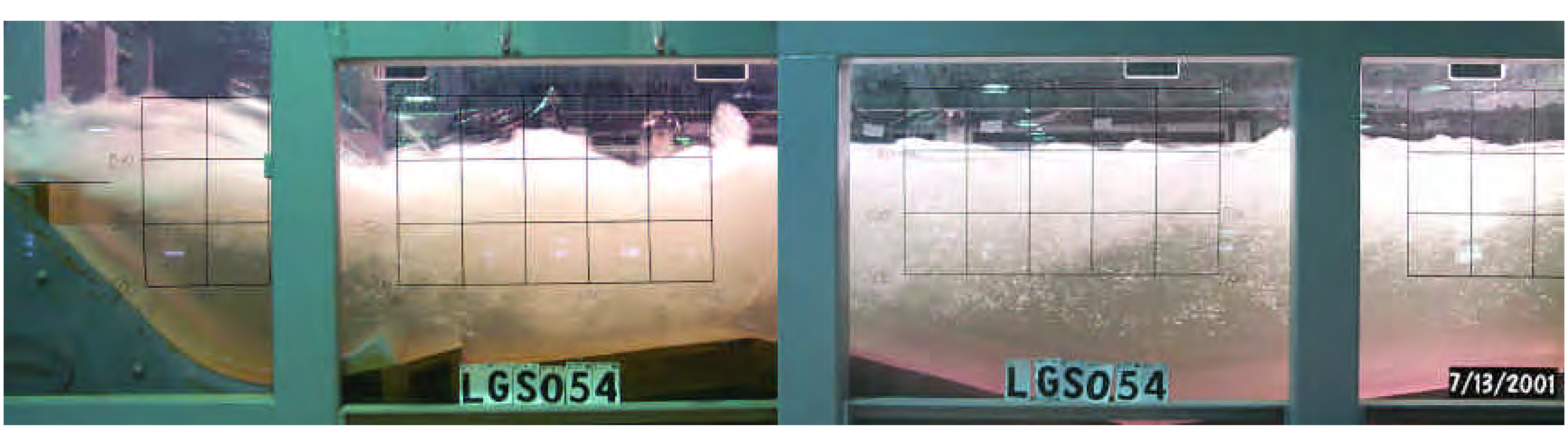


Figure C92. Skimming Surface Jet. Type II Deflector. Gate Opening – 10 ft, Discharge – 19583 cfs/bay, Pool El – 639, Tailwater El – 544

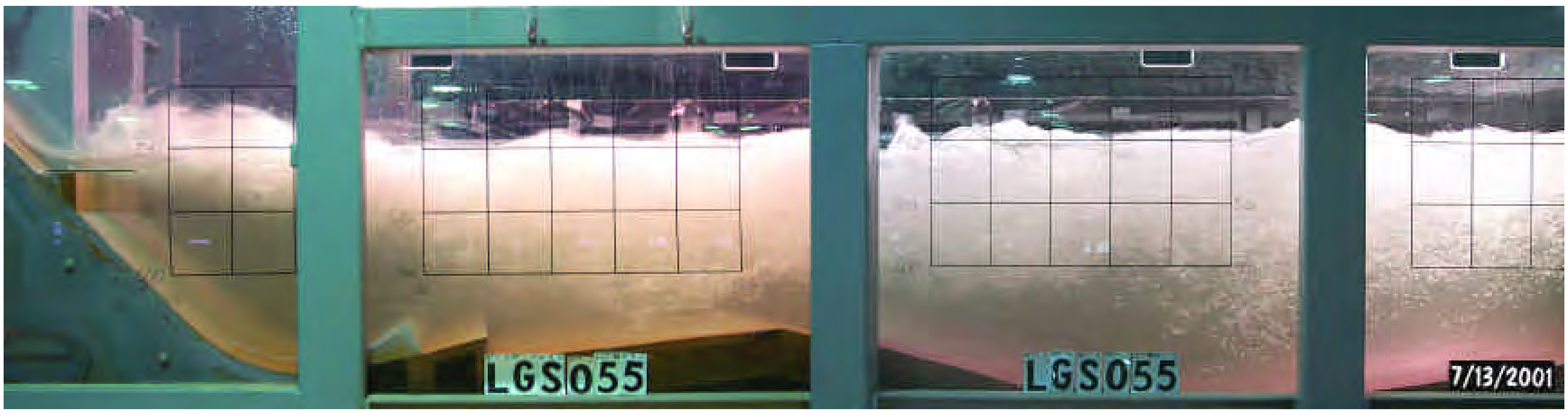


Figure C93. Skimming Surface Jet. Type II Deflector. Gate Opening – 10 ft, Discharge – 19583 cfs/bay, Pool El – 639, Tailwater El – 546

Figure C94. Skimming Surface Jet. Type II Deflector. Gate Opening – 10 ft, Discharge – 19583 cfs/bay, Pool El – 639, Tailwater El – 548

Figure C95. Plunging Flow. Type II Deflector. Gate Opening – 8 ft, Discharge – 15960 cfs/bay, Pool El – 639, Tailwater El – 532

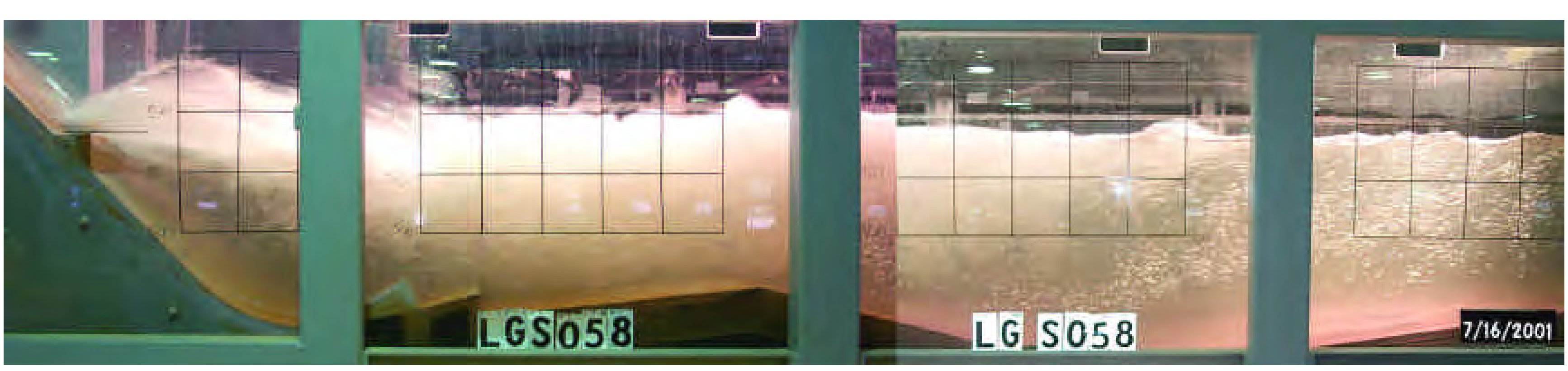


Figure C96. Plunging Flow. Type II Deflector. Gate Opening – 8 ft, Discharge – 15960 cfs/bay, Pool El – 639, Tailwater El – 536

Figure C97. Plunging Flow. Type II Deflector. Gate Opening – 8 ft, Discharge – 15960 cfs/bay, Pool El – 639, Tailwater El – 540

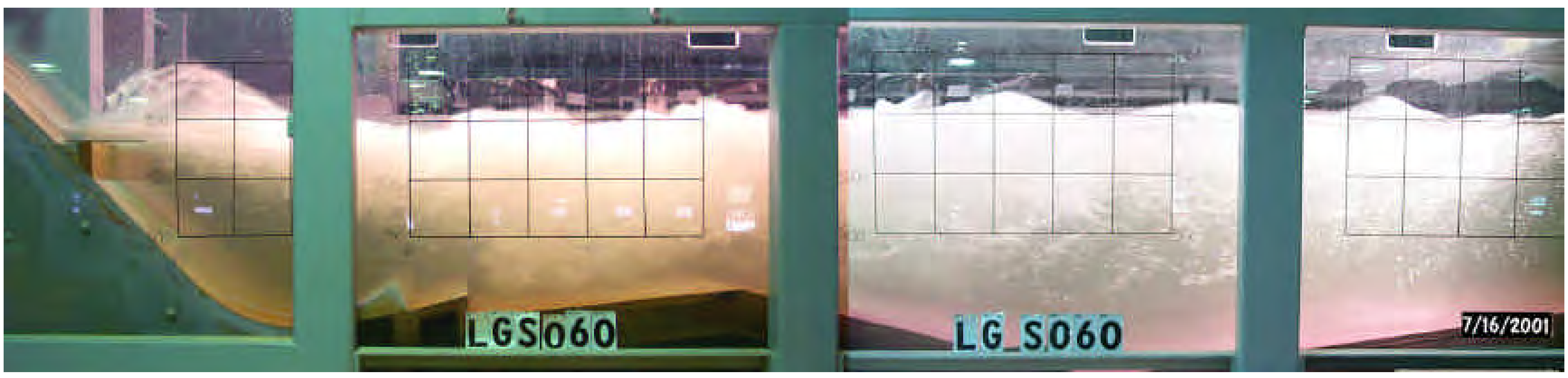


Figure C98. Unstable Plunging Jet. Type II Deflector. Gate Opening – 8 ft, Discharge – 15960 cfs/bay, Pool El – 639, Tailwater El – 542

Figure C99. Skimming Surface Jet. Type II Deflector. Gate Opening – 8 ft, Discharge – 15960 cfs/bay, Pool El – 639, Tailwater El – 544

Figure C100. Skimming Surface Jet. Type II Deflector. Gate Opening – 8 ft, Discharge – 15960 cfs/bay, Pool El – 639, Tailwater El – 546

Figure C101. Skimming Surface Jet. Type II Deflector. Gate Opening – 8 ft, Discharge – 15960 cfs/bay, Pool El – 639, Tailwater El – 548

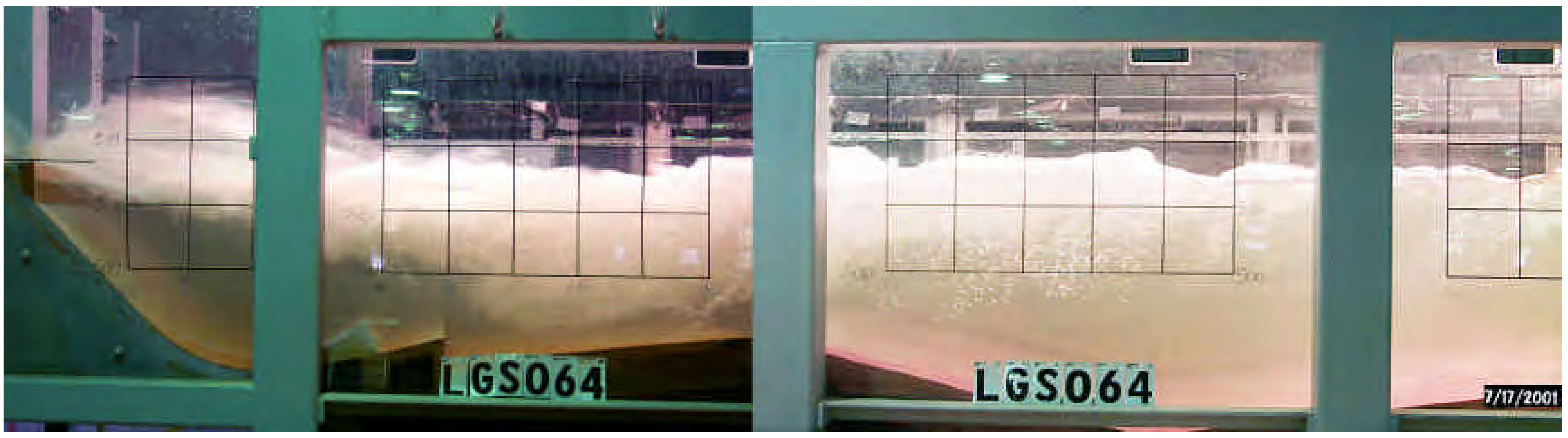


Figure C102. Plunging Jet. Type II Deflector. Gate Opening – 6 ft, Discharge – 12121 cfs/bay, Pool El – 638, Tailwater El – 532

Figure C103. Plunging Flow. Type II Deflector. Gate Opening – 6 ft, Discharge – 12121 cfs/bay, Pool El – 638, Tailwater El – 536

Figure C104. Skimming Surface Jet. Type II Deflector. Gate Opening – 6 ft, Discharge – 12121 cfs/bay, Pool El – 638, Tailwater El – 540

Figure C105. Skimming Surface Jet. Type II Deflector. Gate Opening – 6 ft, Discharge – 12121 cfs/bay, Pool El – 638, Tailwater El – 542

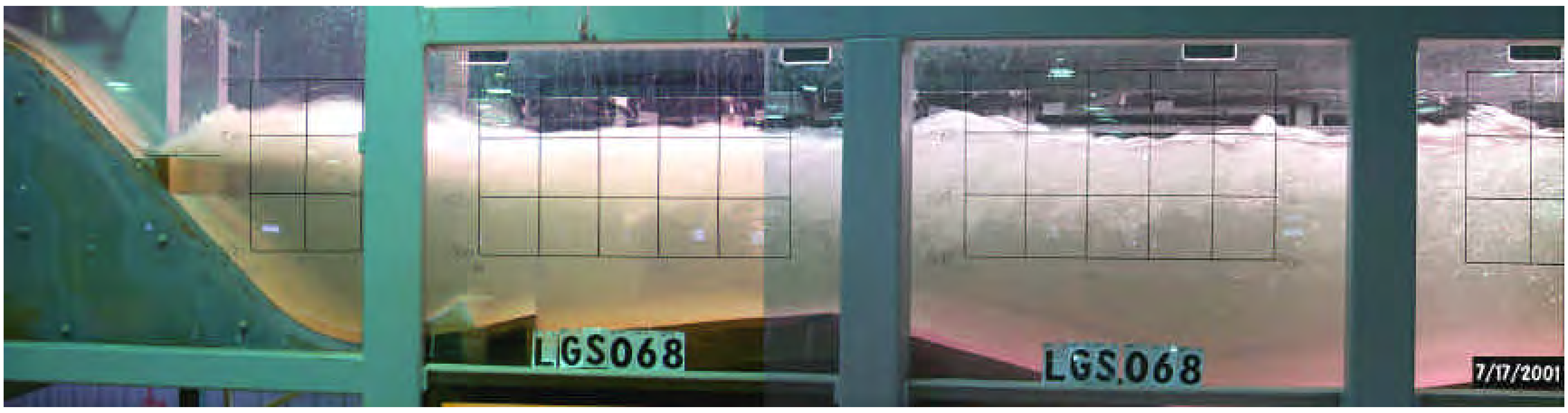


Figure C106. Skimming Surface Jet. Type II Deflector. Gate Opening – 6 ft, Discharge – 12121 cfs/bay, Pool El – 638, Tailwater El – 544

Figure C107. Undulating Surface Jet. Type II Deflector. Gate Opening – 6 ft, Discharge – 12121 cfs/bay, Pool El – 638, Tailwater El – 546

Figure C108. Undulating Surface Jet. Type II Deflector. Gate Opening – 6 ft, Discharge – 12121 cfs/bay, Pool El – 638, Tailwater El – 548

Figure C109. Plunging Flow. Type II Deflector. Gate Opening – 5 ft, Discharge – 9847 cfs/bay, Pool El – 638, Tailwater El – 532

Figure C110. Skimming Surface Jet. Type II Deflector. Gate Opening – 5 ft, Discharge – 9847 cfs/bay, Pool El – 638, Tailwater El – 536

Figure C111. Skimming Surface Jet. Type II Deflector. Gate Opening – 5 ft, Discharge – 9847 cfs/bay, Pool El – 638, Tailwater El – 538

Figure C112. Undulating Surface Jet. Type II Deflector. Gate Opening – 5 ft, Discharge – 9847 cfs/bay, Pool El – 638, Tailwater El – 540

Figure C113. Undulating Surface Jet. Type II Deflector. Gate Opening – 5 ft, Discharge – 9847 cfs/bay, Pool El – 638, Tailwater El – 542

Figure C114. Surface Jump. Type II Deflector. Gate Opening – 5 ft, Discharge – 9847 cfs/bay, Pool El – 638, Tailwater El – 544

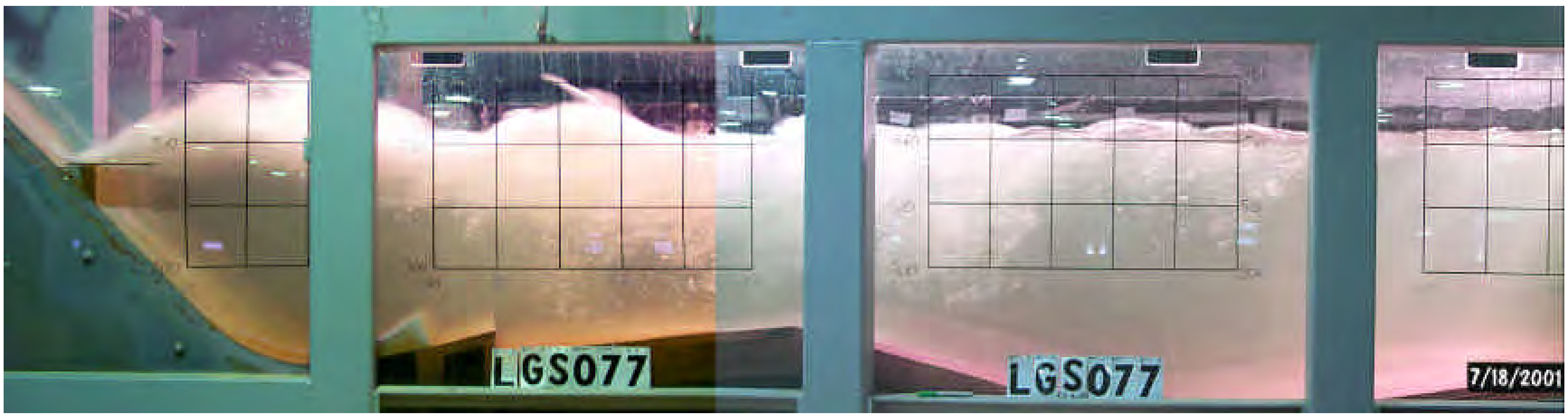


Figure C115. Surface Jump. Type II Deflector. Gate Opening – 5 ft, Discharge – 9847 cfs/bay, Pool El – 638, Tailwater El – 546

Figure C116. Surface Jump. Type II Deflector. Gate Opening – 5 ft, Discharge – 9847 cfs/bay, Pool El – 638, Tailwater El – 548

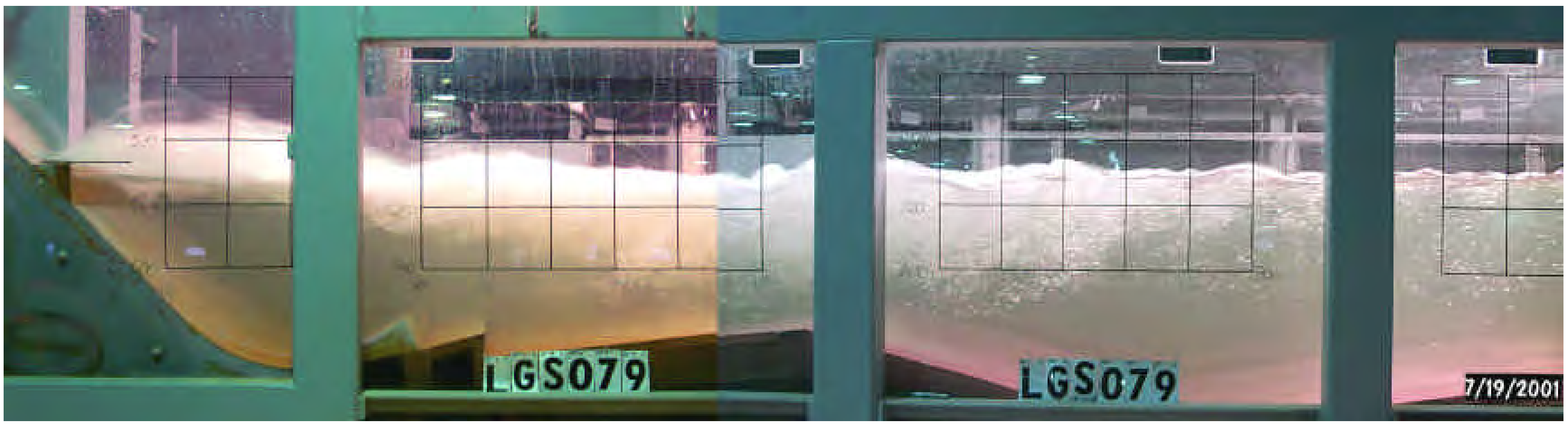


Figure C117. Plunging Flow. Type II Deflector. Gate Opening – 4 ft, Discharge – 8597 cfs/bay, Pool El – 638, Tailwater El – 532

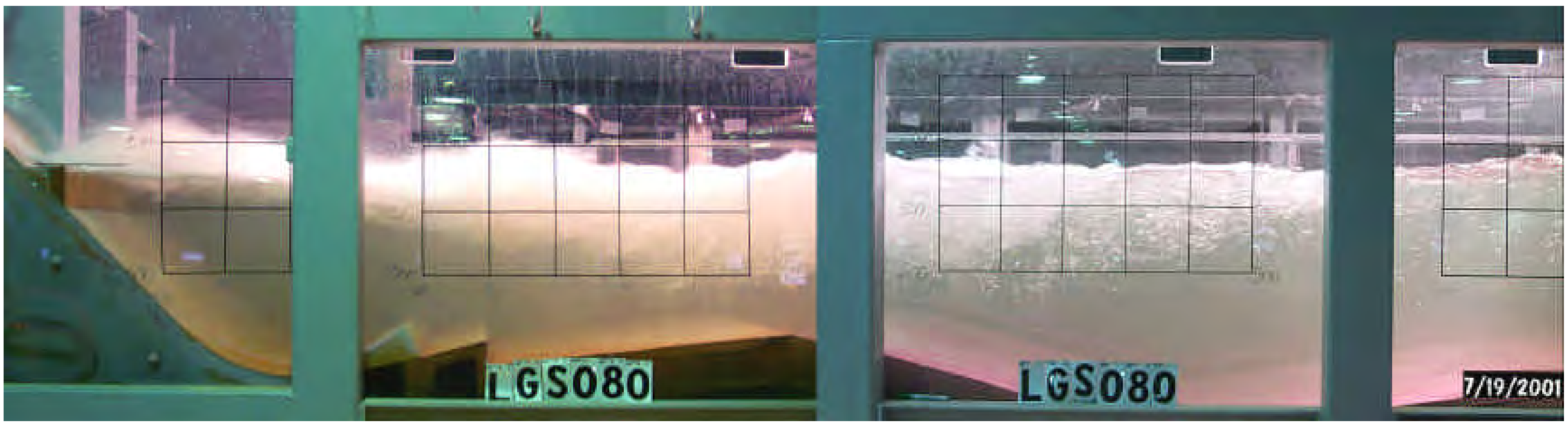


Figure C118. Plunging Flow. Type II Deflector. Gate Opening – 4 ft, Discharge – 8597 cfs/bay, Pool El – 638, Tailwater El – 534

Figure C119. Skimming Surface Jet. Type II Deflector. Gate Opening – 4 ft, Discharge – 8597 cfs/bay, Pool El – 638, Tailwater El – 536

Figure C120. Skimming Surface Jet. Type II Deflector. Gate Opening – 4 ft, Discharge – 8597 cfs/bay, Pool El – 638, Tailwater El – 538

Figure C121. Undulating Surface Jet. Type II Deflector. Gate Opening – 4 ft, Discharge – 8597 cfs/bay, Pool El – 638, Tailwater El – 540

Figure C122. Undulating Surface Jet. Type II Deflector. Gate Opening – 4 ft, Discharge – 8597 cfs/bay, Pool El – 638, Tailwater El – 542

Figure C123. Ramped Surface Jet. Type II Deflector. Gate Opening – 4 ft, Discharge – 8597 cfs/bay, Pool El – 638, Tailwater El – 544

Figure C124. Surface Jump. Type II Deflector. Gate Opening – 4 ft, Discharge – 8597 cfs/bay, Pool El – 638, Tailwater El – 546

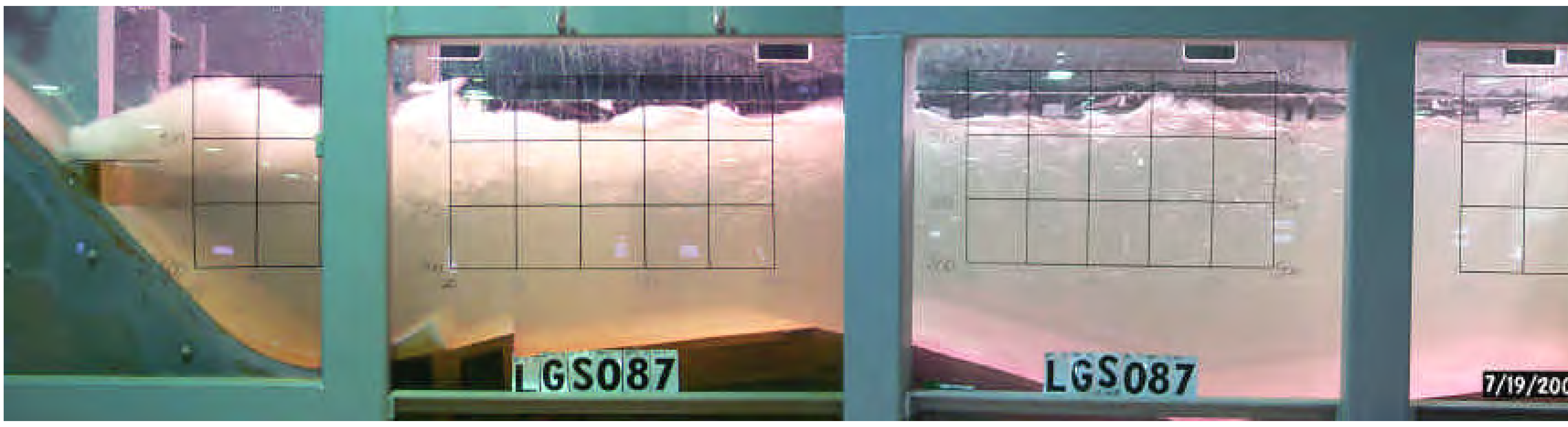


Figure C125. Surface Jump. Type II Deflector. Gate Opening – 4 ft, Discharge – 8597 cfs/bay, Pool El – 638, Tailwater El – 548

Figure C126. Plunging Flow. Type II Deflector. Gate Opening – 2 ft, Discharge – 4559 cfs/bay, Pool El – 638, Tailwater El – 532

Figure C127. Skimming Surface Jet. Type II Deflector. Gate Opening – 2 ft, Discharge – 4559 cfs/bay, Pool El – 638, Tailwater El – 534

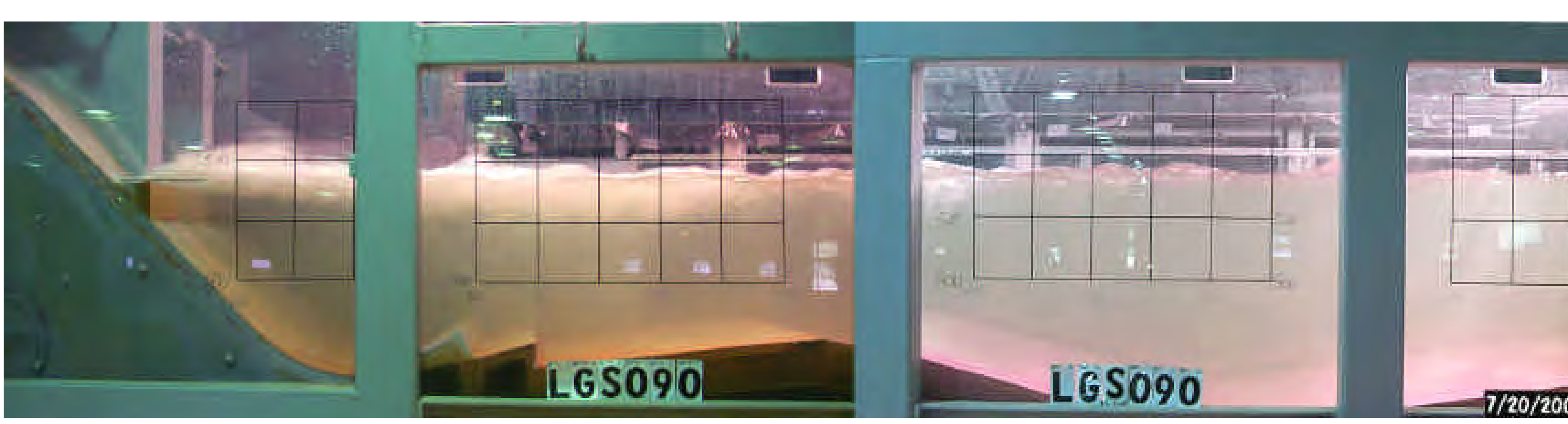


Figure C128. Skimming Surface Jet. Type II Deflector. Gate Opening – 2 ft, Discharge – 4559 cfs/bay, Pool El – 638, Tailwater El – 536

Figure C129. Undulating Surface Jet. Type II Deflector. Gate Opening – 2 ft, Discharge – 4559 cfs/bay, Pool El – 638, Tailwater El – 538

Figure C130. Undulating Surface Jet. Type II Deflector. Gate Opening – 2 ft, Discharge – 4559 cfs/bay, Pool El – 638, Tailwater El – 540

Figure C131. Surface Jump. Type II Deflector. Gate Opening – 2 ft, Discharge – 4559 cfs/bay, Pool El – 638, Tailwater El – 542

Figure C132. Surface Jump. Type II Deflector. Gate Opening – 2 ft, Discharge – 4559 cfs/bay, Pool El – 638, Tailwater El – 544

Figure C133. Submerged Surface Jump. Type II Deflector. Gate Opening – 2 ft, Discharge – 4559 cfs/bay, Pool El – 638, Tailwater El – 546

Figure C134. Submerged Surface Jump. Type II Deflector. Gate Opening – 2 ft, Discharge – 4559 cfs/bay, Pool El – 638, Tailwater El – 548

Figure C135. Skimming Flow. Type IIb Deflector. Gate Opening – 10 ft, Discharge – 19621 cfs/bay, Pool El – 638, Tailwater El – 547

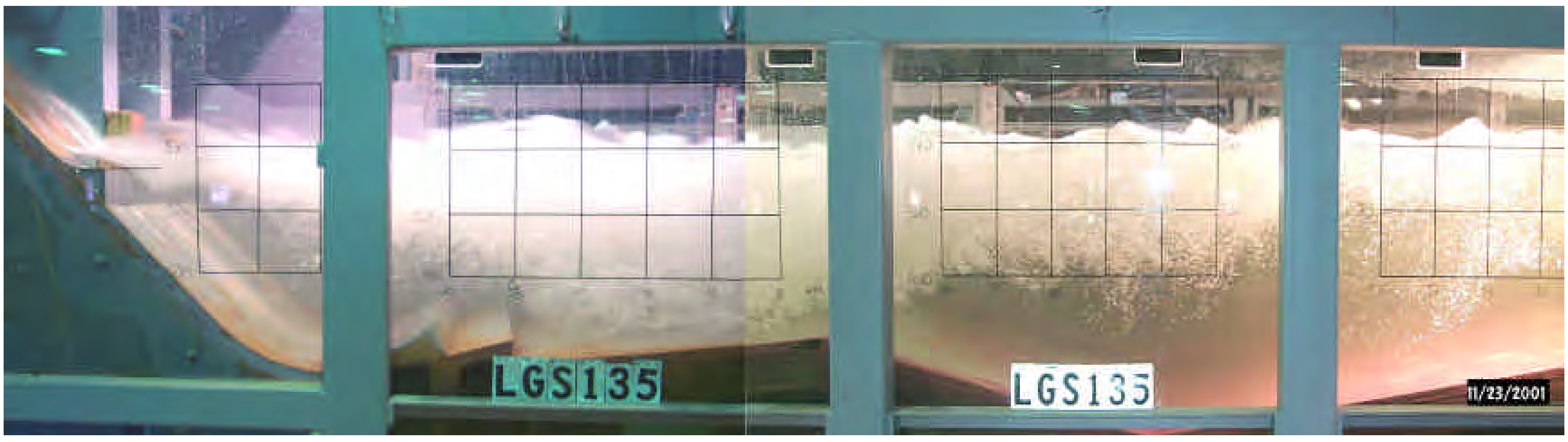


Figure C136. Plunging Flow. Type IIb Deflector. Gate Opening – 10 ft, Discharge – 19621 cfs/bay, Pool El – 638, Tailwater El – 545

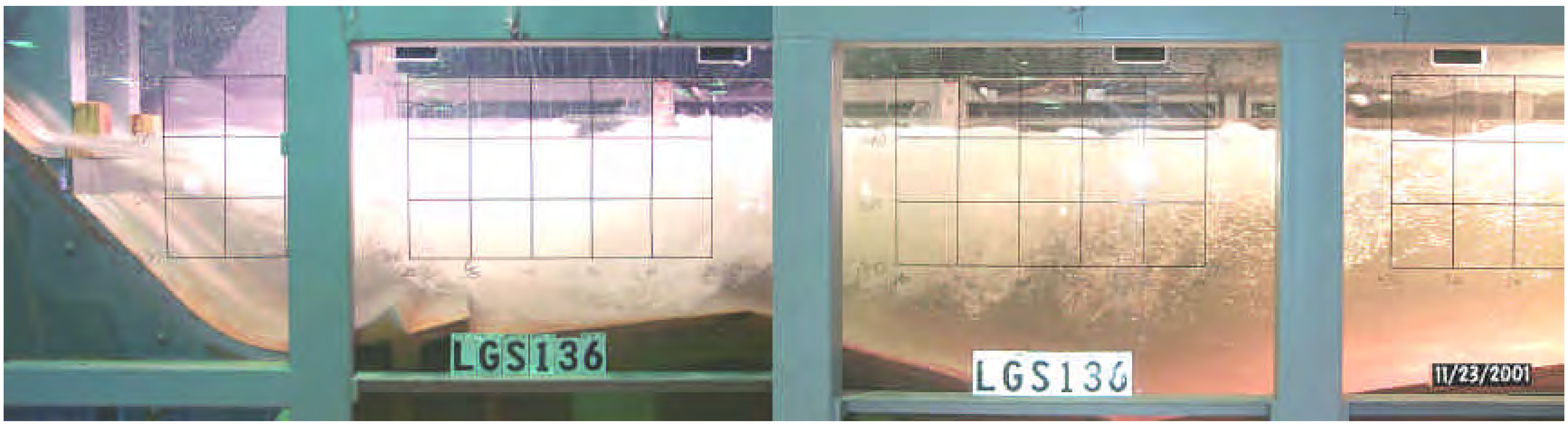


Figure C137. Plunging Flow. Type IIb Deflector. Gate Opening – 10 ft, Discharge – 19621 cfs/bay, Pool El – 638, Tailwater El – 543

Figure C138. Unstable Plunging Jet. Type IIb Deflector. Gate Opening – 12 ft, Discharge – 23731 cfs/bay, Pool El – 638, Tailwater El – 547

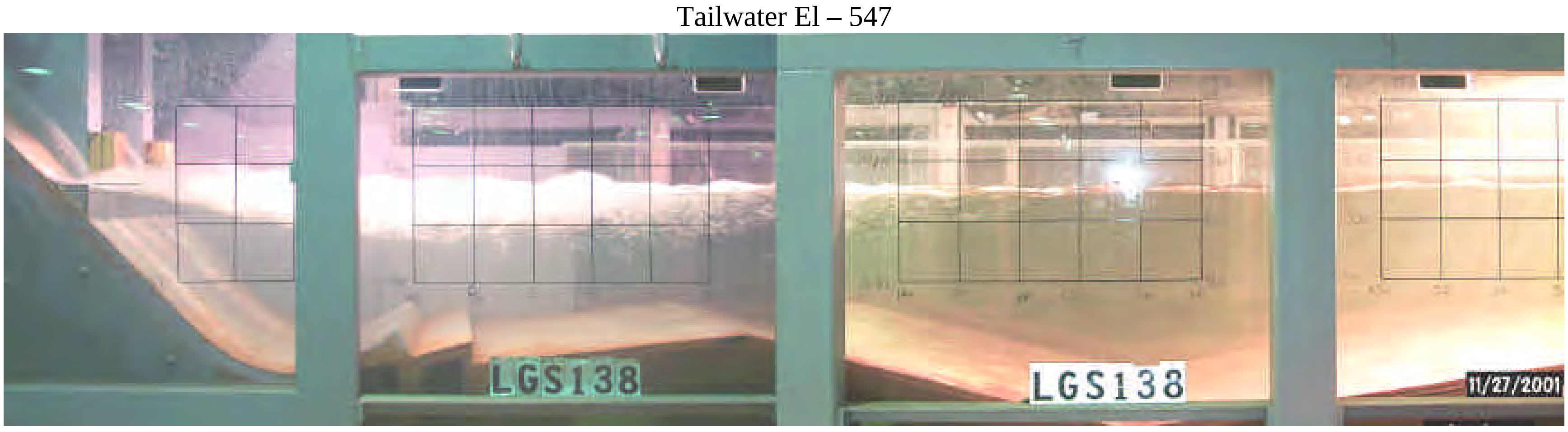


Figure C139. Plunging Flow. Type IIb Deflector. Gate Opening – 2 ft, Discharge – 4361 cfs/bay, Pool El – 638, Tailwater El – 532

Figure C140. Skimming Surface Jet. Type IIb Deflector. Gate Opening – 2 ft, Discharge – 4361 cfs/bay, Pool El – 638, Tailwater El – 534

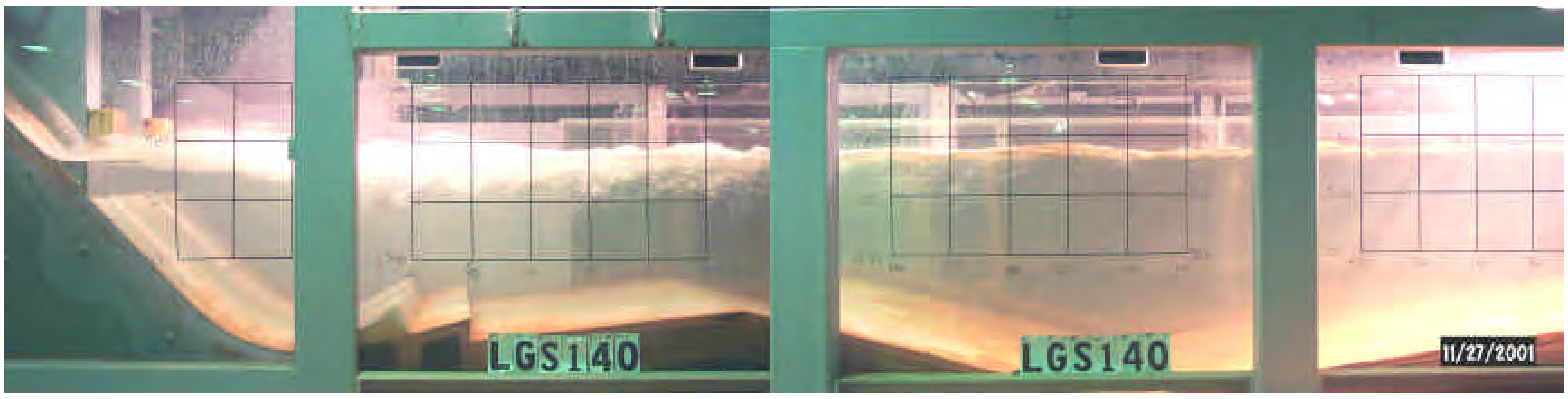


Figure C141. Skimming Surface Jet. Type IIb Deflector. Gate Opening – 2 ft, Discharge – 4361 cfs/bay, Pool El – 638, Tailwater El – 536

Figure C142. Undulating Surface Jet. Type IIb Deflector. Gate Opening – 2 ft, Discharge – 4361 cfs/bay, Pool El – 638, Tailwater El – 538

Figure C143. Ramped Surface Jet. Type IIb Deflector. Gate Opening – 2 ft, Discharge – 4361 cfs/bay, Pool El – 638, Tailwater El – 540

Figure C144. Surface Jump. Type IIb Deflector. Gate Opening – 2 ft, Discharge – 4361 cfs/bay, Pool El – 638, Tailwater El – 542

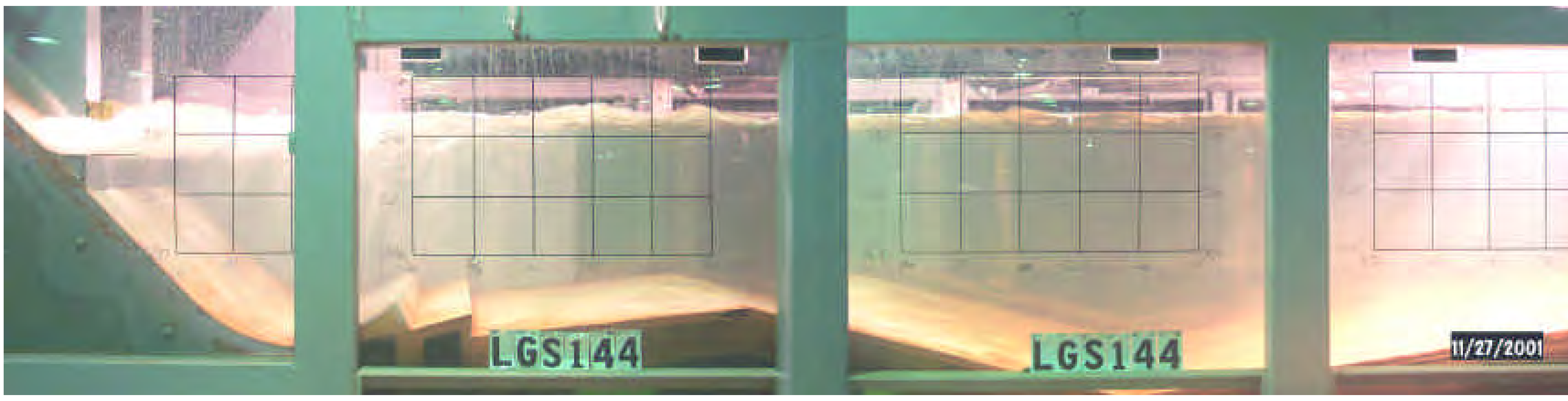


Figure C145. Submerged Surface Jump. Type IIb Deflector. Gate Opening – 2 ft, Discharge – 4361 cfs/bay, Pool El – 638, Tailwater El – 546

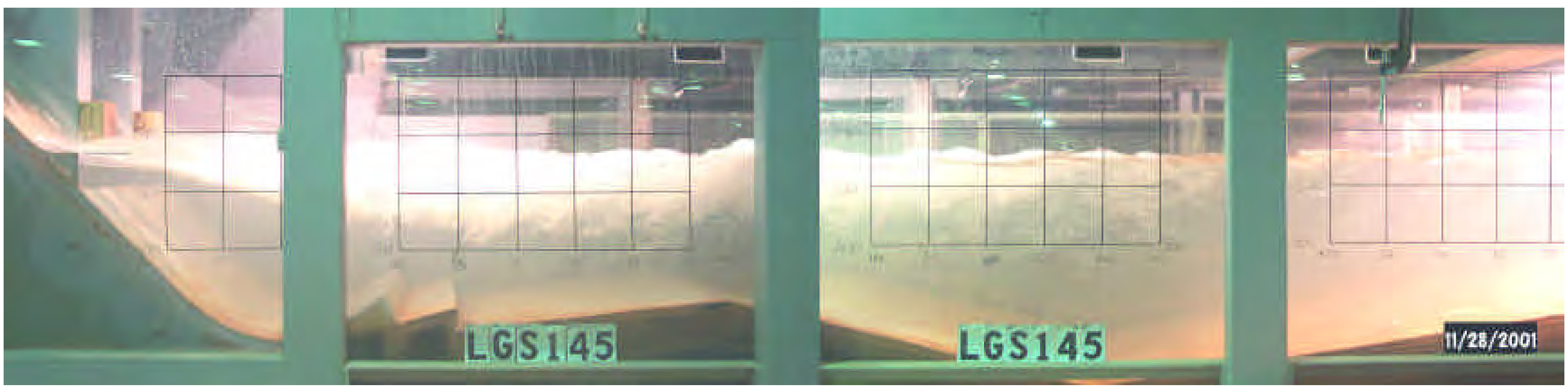


Figure C146. Plunging Flow. Type IIb Deflector. Gate Opening – 4 ft, Discharge – 8093 cfs/bay, Pool El – 638, Tailwater El – 532

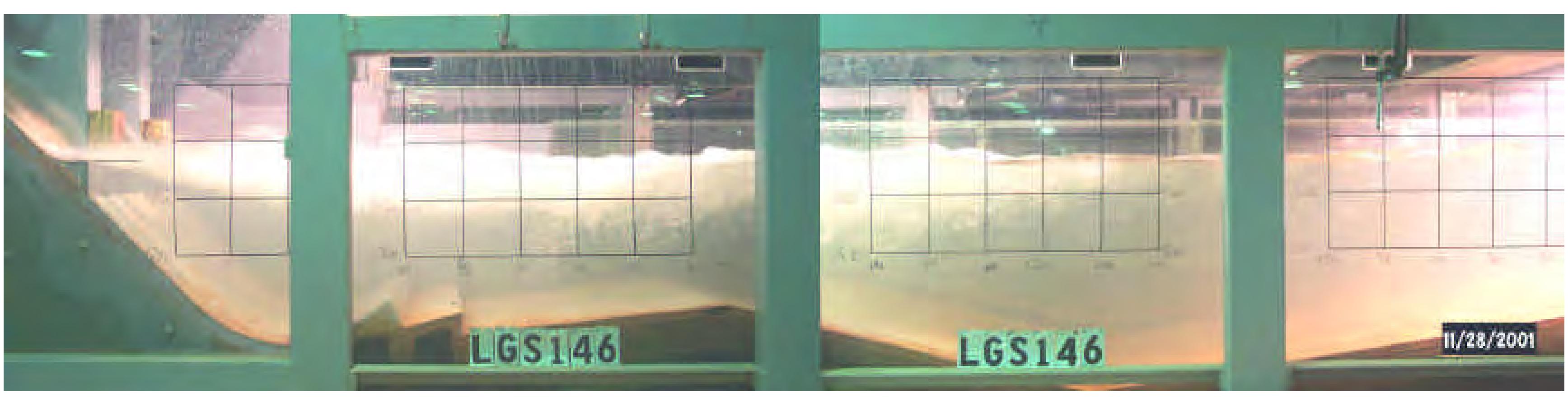


Figure C147. Plunging Flow. Type IIb Deflector. Gate Opening – 4 ft, Discharge – 8093 cfs/bay, Pool El – 638, Tailwater El – 535

Figure C148. Skimming Surface Jet. Type IIb Deflector. Gate Opening – 4 ft, Discharge – 8215 cfs/bay, Pool El – 638, Tailwater El – 536

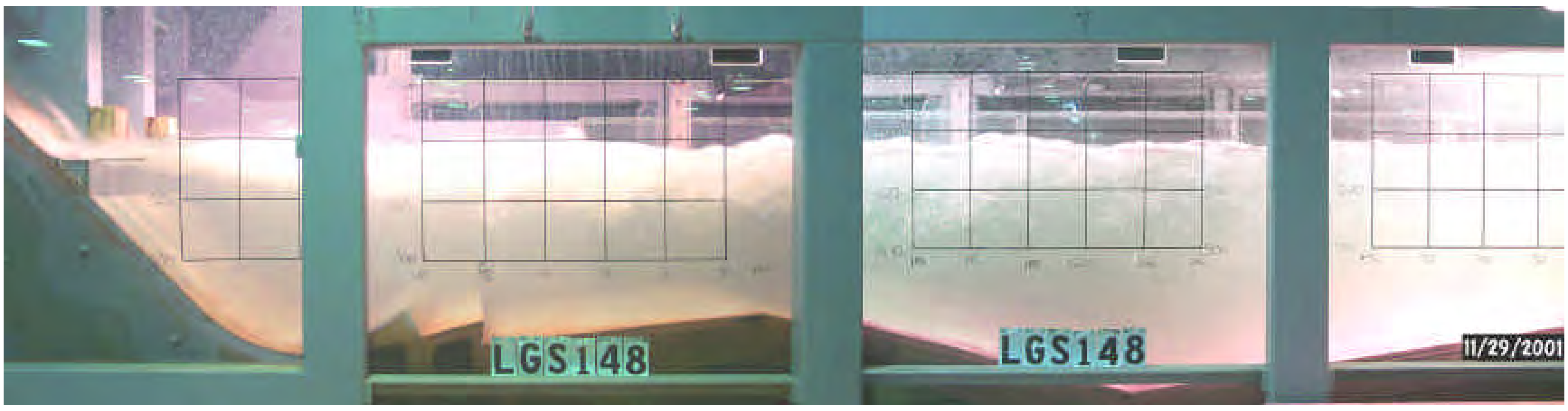


Figure C149. Skimming Surface Jet. Type IIb Deflector. Gate Opening – 4 ft, Discharge – 8215 cfs/bay, Pool El – 638, Tailwater El – 538

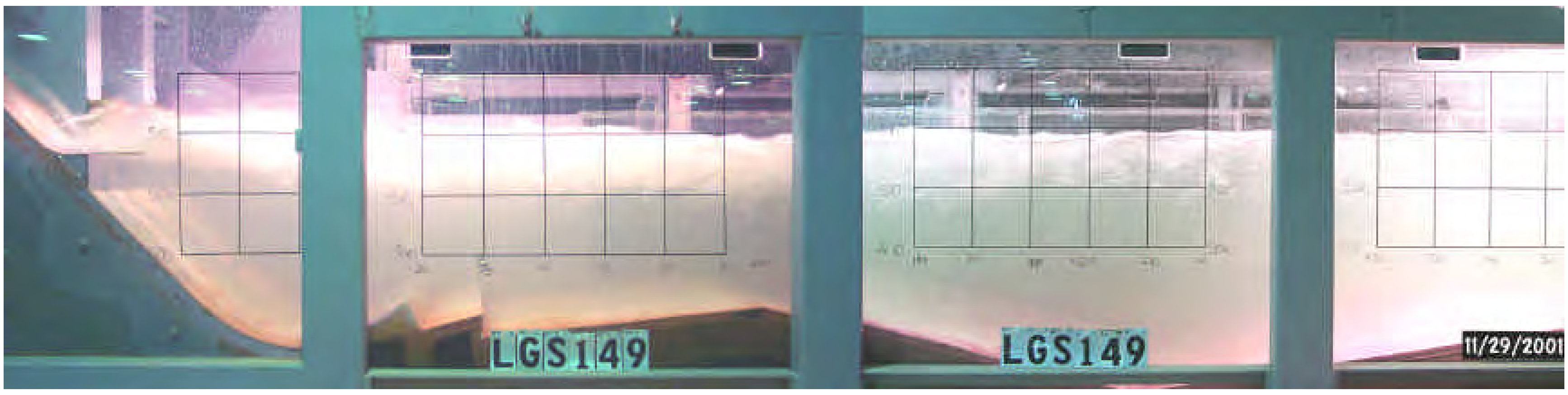


Figure C150. Undulating Surface Jet. Type IIb Deflector. Gate Opening – 4 ft, Discharge – 8215 cfs/bay, Pool El – 638, Tailwater El – 540

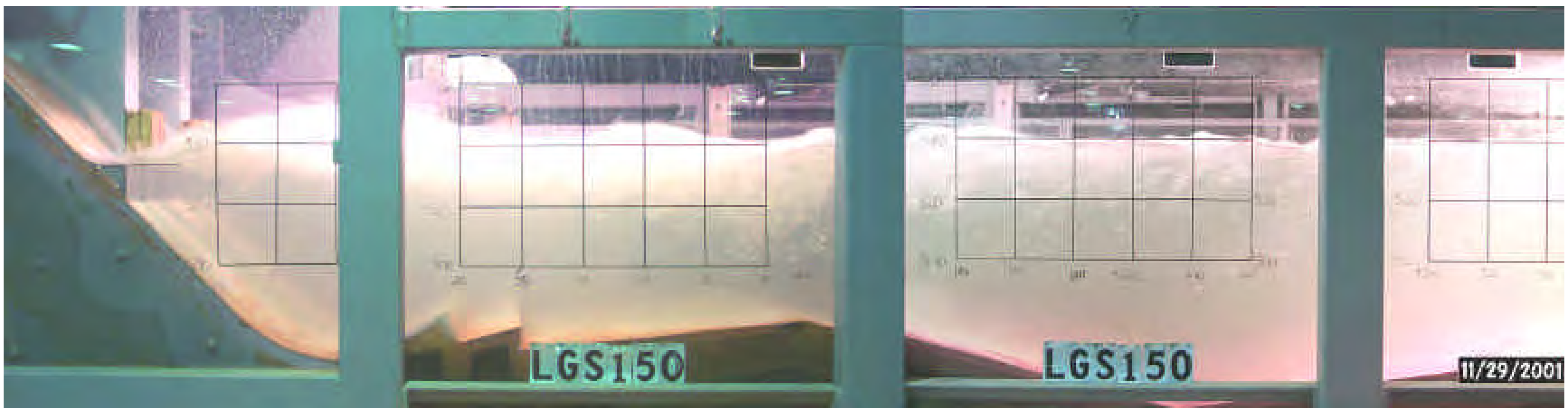


Figure C151. Ramped Surface Jet. Type IIb Deflector. Gate Opening – 4 ft, Discharge – 8215 cfs/bay, Pool El – 638, Tailwater El – 542

Figure C152. Surface Jump. Type IIb Deflector. Gate Opening – 4 ft, Discharge – 8215 cfs/bay, Pool El – 638, Tailwater El – 546

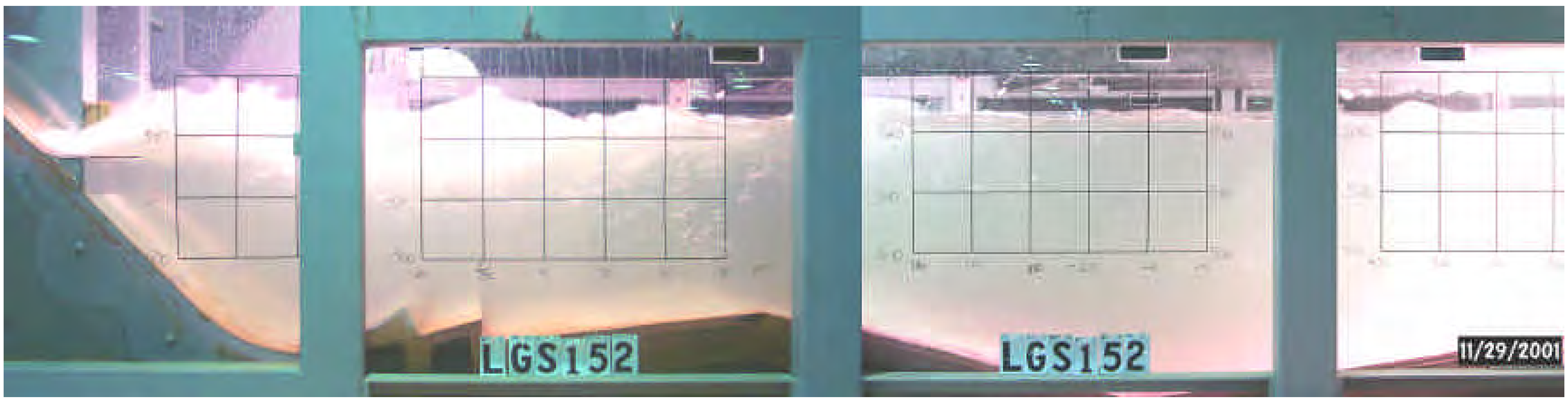


Figure C153. Submerged Surface Jump. Type IIb Deflector. Gate Opening – 4 ft, Discharge – 8215 cfs/bay, Pool El – 638, Tailwater El – 547

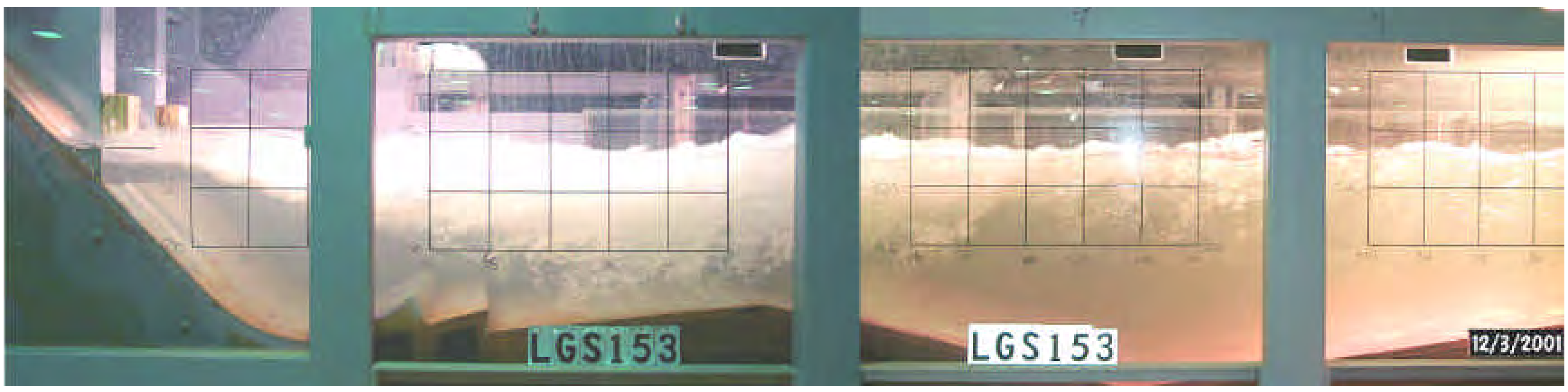


Figure C154. Plunging Flow. Type IIb Deflector. Gate Opening – 6 ft, Discharge – 11832 cfs/bay, Pool El – 638, Tailwater El – 534

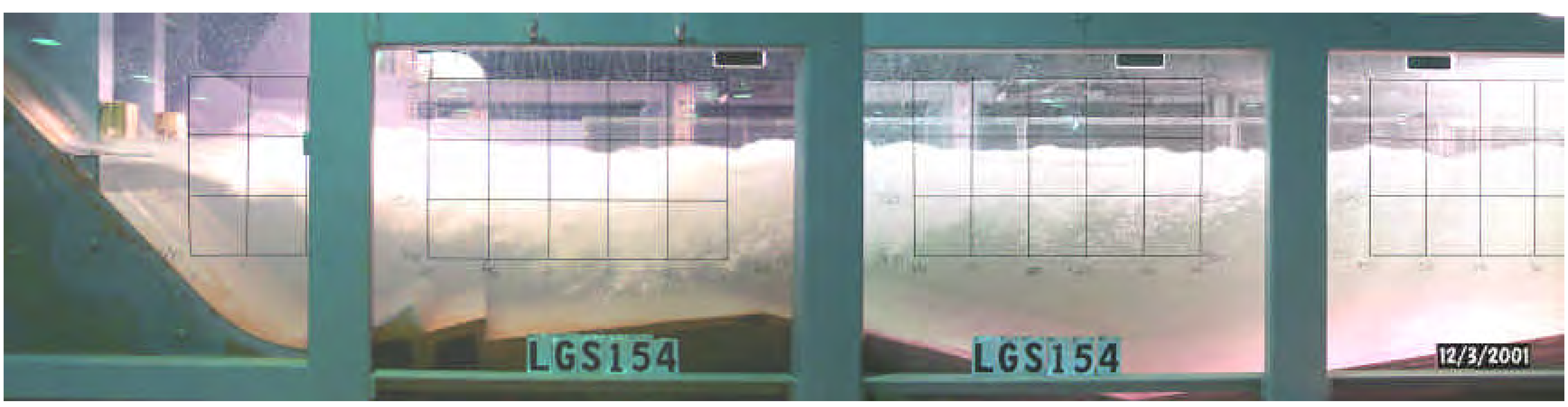


Figure C155. Plunging Flow. Type IIb Deflector. Gate Opening – 6 ft, Discharge – 11832 cfs/bay, Pool El – 638, Tailwater El – 536

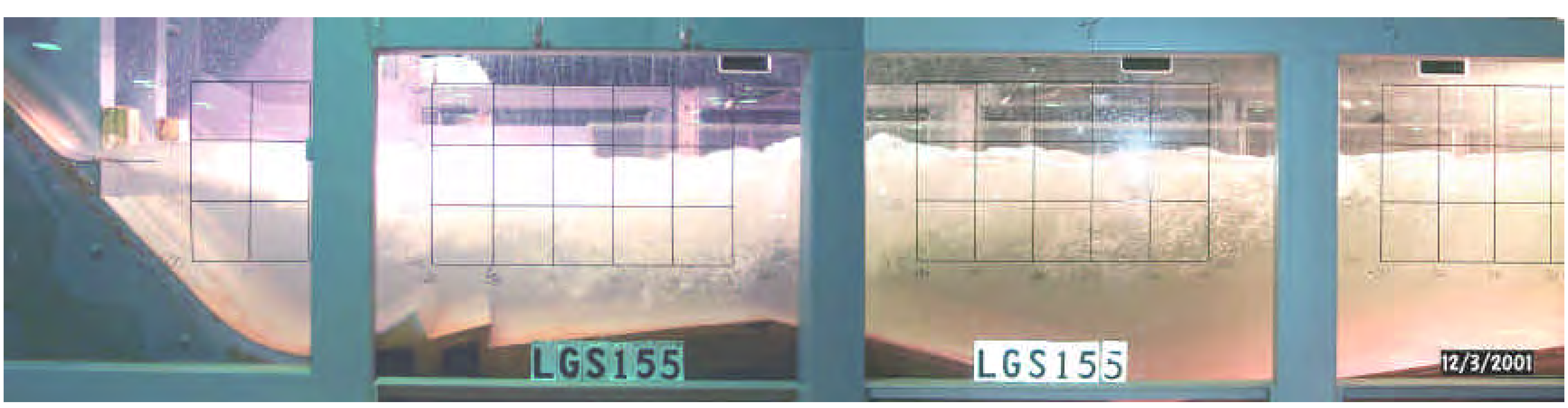


Figure C156. Plunging Flow. Type IIb Deflector. Gate Opening – 6 ft, Discharge – 11832 cfs/bay, Pool El – 638, Tailwater El – 538

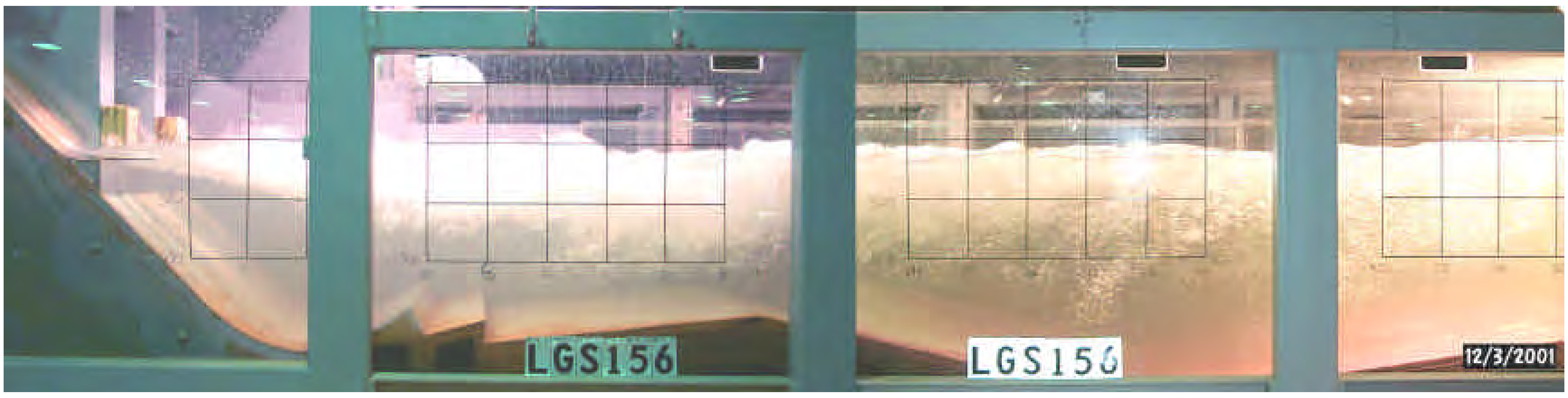


Figure C157. Skimming Surface Jet. Type IIb Deflector. Gate Opening – 6 ft, Discharge – 11832 cfs/bay, Pool El – 638, Tailwater El – 539

Figure C158. Skimming Surface Jet. Type IIb Deflector. Gate Opening – 6 ft, Discharge – 11832 cfs/bay, Pool El – 638, Tailwater El – 541

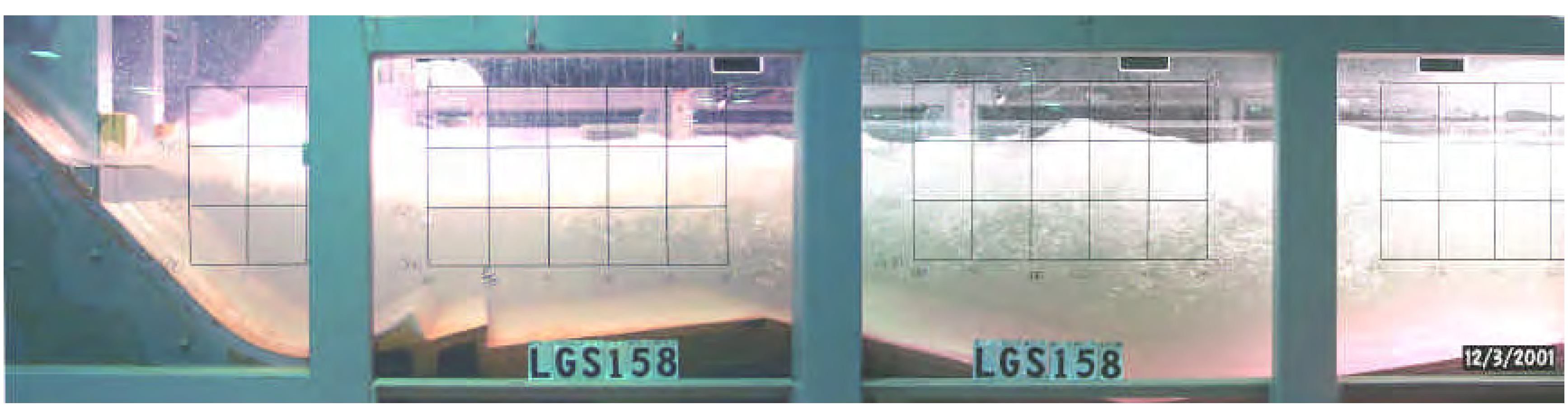


Figure C159. Undulating Surface Jet. Type IIb Deflector. Gate Opening – 6 ft, Discharge – 11832 cfs/bay, Pool El – 638, Tailwater El – 543

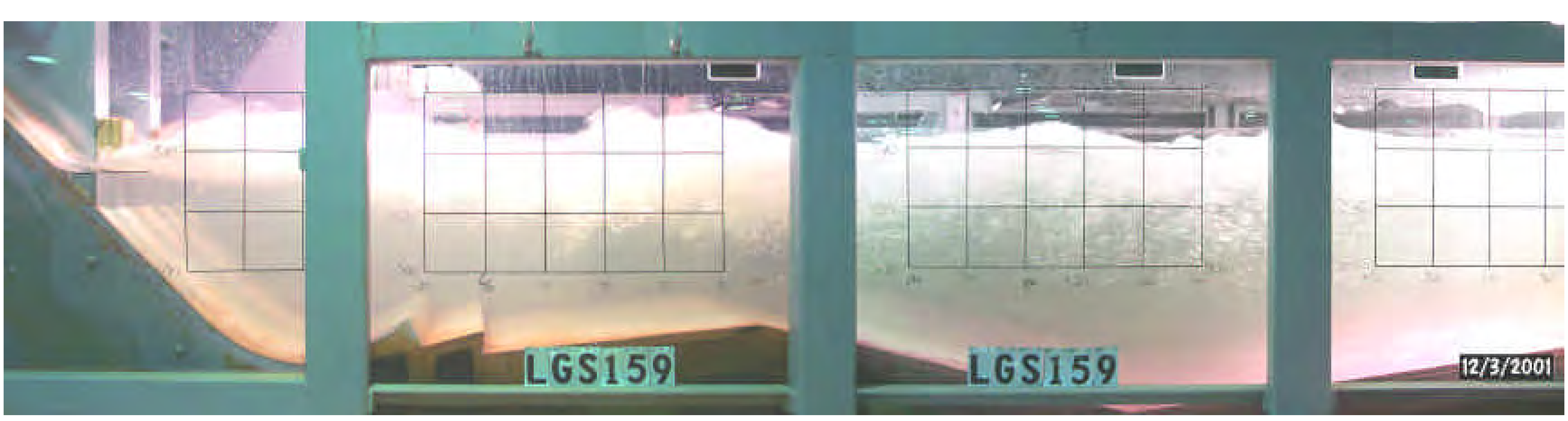


Figure C160. Ramped Surface Jet. Type IIb Deflector. Gate Opening – 6 ft, Discharge – 11832 cfs/bay, Pool El – 638, Tailwater El – 545

Figure C161. Surface Jump. Type IIb Deflector. Gate Opening – 6 ft, Discharge – 11832 cfs/bay, Pool El – 638, Tailwater El – 547

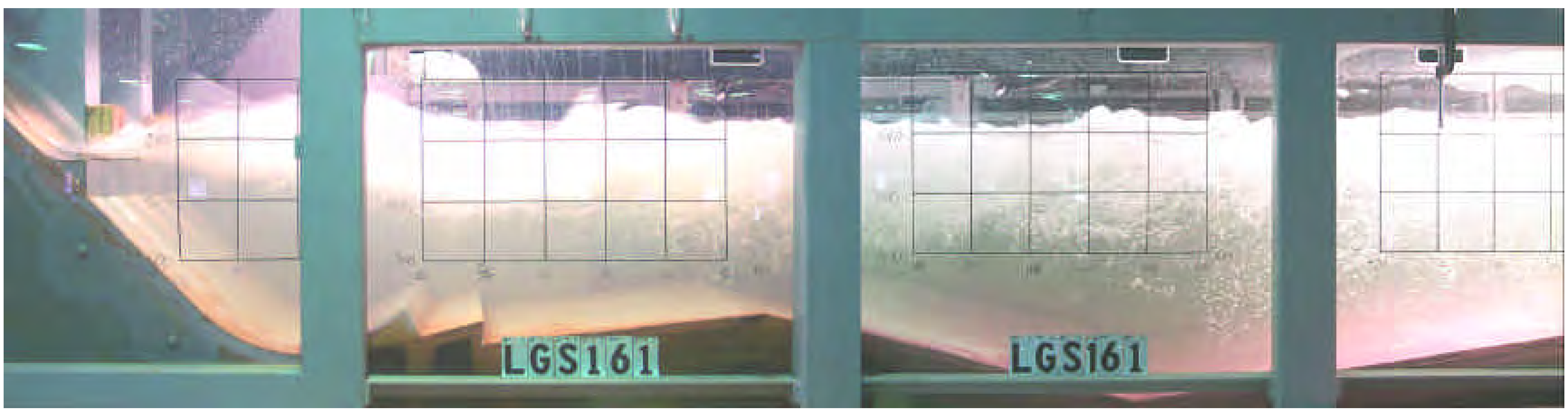


Figure C162. Undulating Surface Jet. Type IIb Deflector. Gate Opening – 8 ft, Discharge – 15423 cfs/bay, Pool El – 638, Tailwater El – 547

Figure C163. Skimming Surface Jet. Type IIb Deflector. Gate Opening – 8 ft, Discharge – 15423 cfs/bay, Pool El – 638, Tailwater El – 545

Figure C164. Skimming Surface Jet. Type IIb Deflector. Gate Opening – 8 ft, Discharge – 15423 cfs/bay, Pool El – 638, Tailwater El – 543

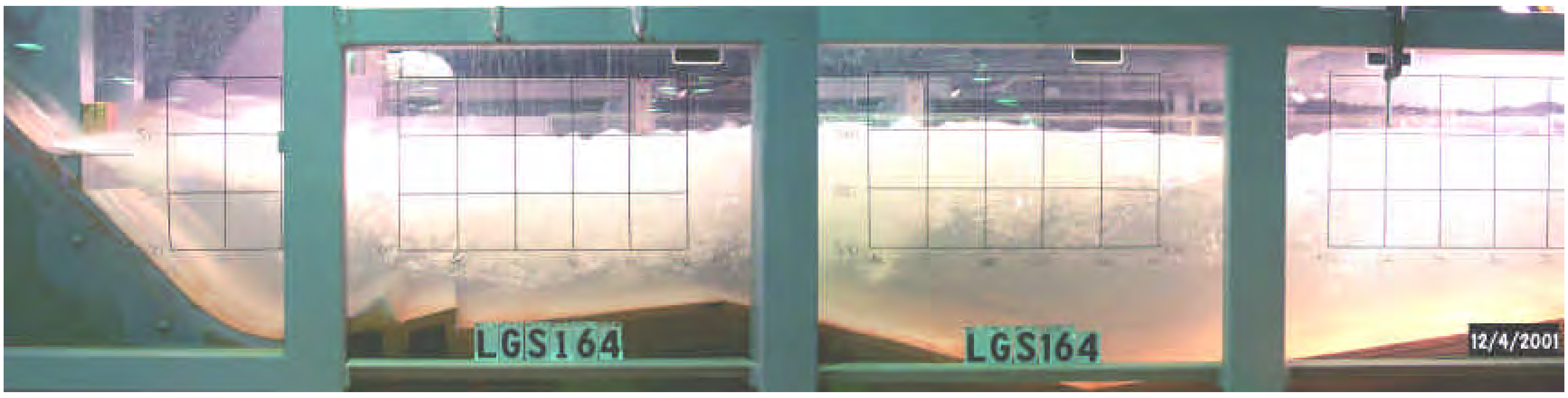


Figure C165. Plunging Flow. Type IIb Deflector. Gate Opening – 8 ft, Discharge – 15423 cfs/bay, Pool El – 638, Tailwater El – 541

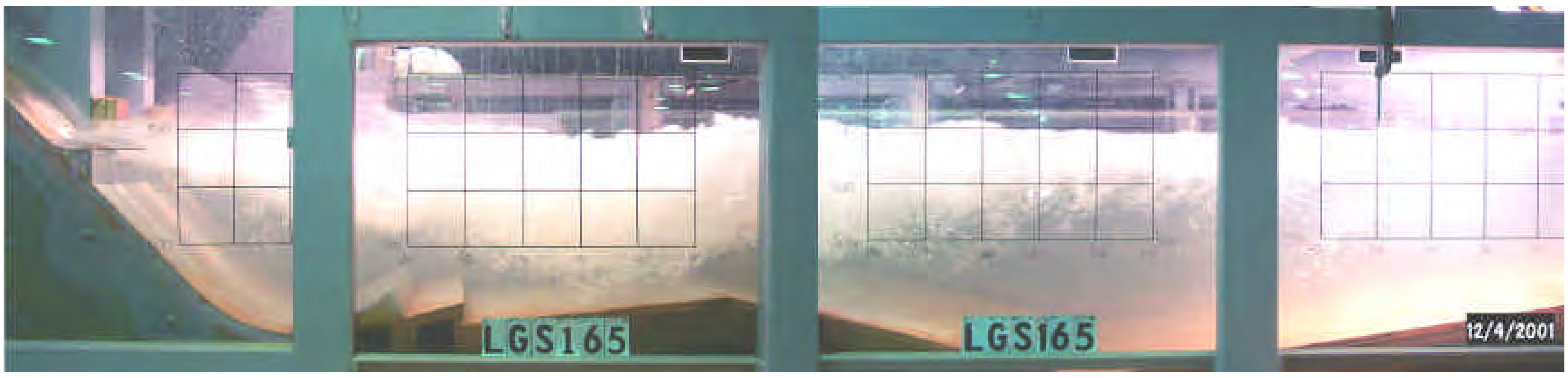
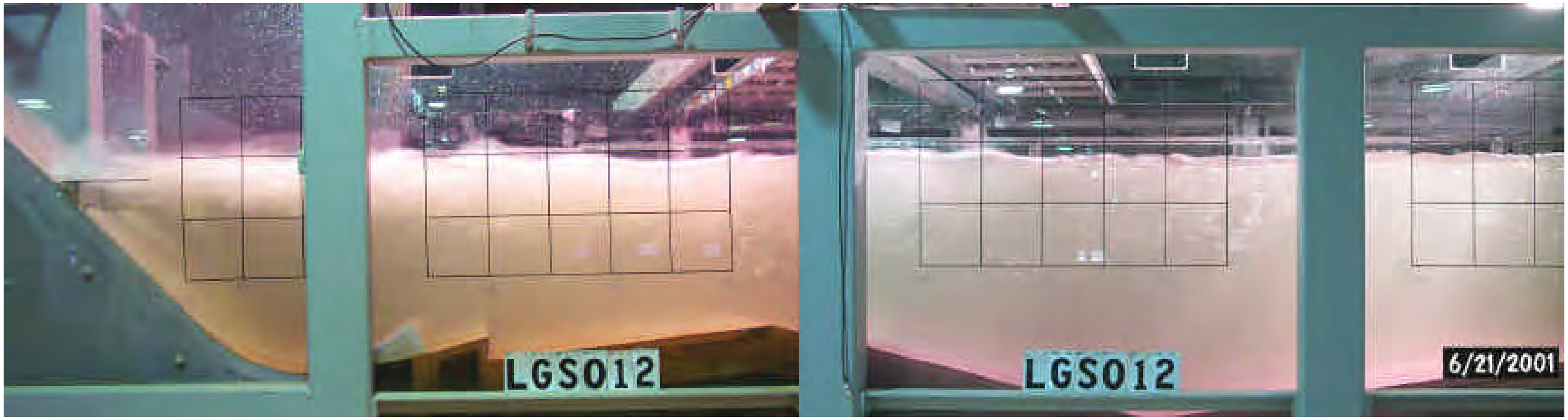


Figure C166. Plunging Flow. Type IIb Deflector. Gate Opening – 8 ft, Discharge – 15423 cfs/bay, Pool El – 638, Tailwater El – 539

CLICK PHOTO TO VIEW VIDEO 1



Skimming Surface Jet. Gate Opening = 4 ft, Discharge = 8597 cfs/bay, Pool El = 638, Tailwater El = 538

CLICK PHOTO TO VIEW VIDEO 2

Skimming Surface Jet. Gate Opening = 10 ft, Discharge = 19583 cfs/bay,
Pool El = 638, Tailwater El = 547

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14. ABSTRACT
Based on the results of the Dissolved Gas Abatement Studies, spillway deflectors were recommended for the exterior bays of the Little Goose Spillway to reduce total dissolved gas production during spill operations. The design of the deflectors was developed by examining their hydraulic performance in a 1:40-scale section model of the spillway. Four different deflector designs were compared relative to flow conditions in the stilling basin and tailrace area of the section model. The authors recommend the design of the existing deflector, designated Type I, which is 8 feet (ft) long at elevation 532.0 (National Geodetic Vertical Datum) with no transition radius for the exterior bays at Little Goose Spillway. There was essentially no difference in the performance character of the Type I deflector and the Type II deflector (12 ft long without transition radius) over the design discharge range of 7,000–10,000 cubic feet per second per spill bay. Velocities, as high as 17 ft/second, were measured along the tailrace channel bottom. Detailed hydrographic survey data should be taken in the stilling basin and tailrace to assess changes in bathymetry caused by potential scour or ball-mill grinding.

15. SUBJECT TERMS
Hydraulics, Hydraulic structures, Little Goose Lock and Dam, Spillways—Design and construction, Snake River (Wyo.-Wash.), Water—Nitrogen content, Water—Dissolved oxygen, Water quality

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